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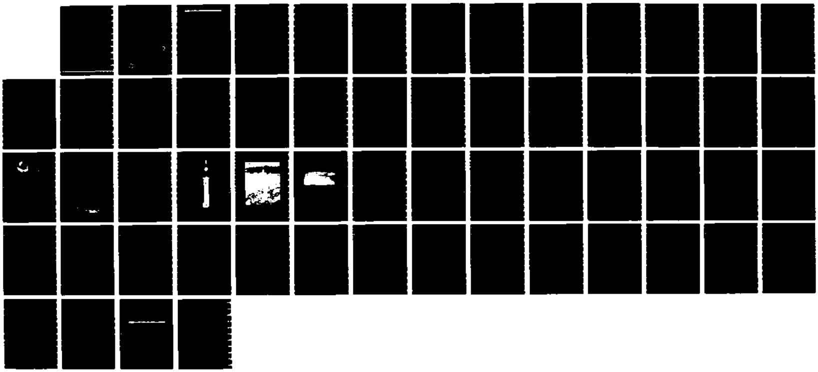

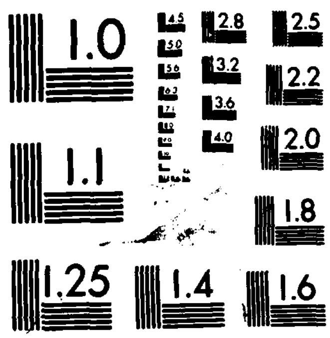
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Ship Performance Department
Test and Evaluation Report

FIELD MEASUREMENTS OF NEARSHORE WAVE ENVIRONMENT AT CAPE CANAVERAL, FLORIDA AND KINGS BAY, GEORGIA

by
R.J. Lai
E.W. Foley

DTNSRDC/SPD-1190-02 Field Measurements of Nearshore Wave Environment at Cape Canaveral, Florida and Kings Bay, Georgia

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Two wave measuring systems have been installed at Cape Canaveral, Florida and Kings Bay, Georgia, respectively. The technique required to continuously measure waves in a nearshore zone for a long period of time often involves problems different from those encountered when measuring in deep water. The instruments used for the systems, selection of the sites, installation and retrieval procedures, and data analysis have been reported here.

The measurement program started at Cape Canaveral and was later applied to Kings Bay. The systems were upgraded to measure directional waves in December 1983. Among the wave measuring systems, three measure directional wave spectra, mean currents and water depths. The quality of data and data recovery rate of each system at a specific site have been evaluated and reported here. Some hardware modifications have been made to ensure the operation of the instruments and to achieve a higher data recovery rate.

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

NOTATION

a_1, a_2	Fourier coefficient in the spreading function
b_1, b_2	Fourier coefficient in the spreading function
$E(f, \theta)$	Wave energy
E_J	JONSWAP spectrum
E_P	Phillips equilibrium range spectrum
E_W	Wallops spectrum
f	Wave frequency in Hz
f_o	Wave modal frequency
h	Water depth
$H(f, \theta)$	Directional spreading function
K	Wave number
m	Wave slope in Wallops spectrum
P	Water pressure
R_n	Combined Fourier coefficients in the spreading function
U	Wave particle velocity in east-west direction
U_w	Current speed
U_n	Coastal wind velocity
U_o	Offshore wind velocity
V	Wave particle velocity in north-south direction
W_n	Weighting factors in spreading function
α	Phillips spectral constant
β	Wallops spectral constant
γ	Peak enhancement factor of JONSWAP spectrum
θ	Mean wave direction
θ_1, θ_2	Mean wave directional from first and second harmonic coefficients

θ^*	RMS spreading angle
σ	JONSWAP spectral constant
Γ	Gamma function
ϕ_{PM}	Shape function by Pierson and Moskowitz
ϕ_J	JONSWAP shape function
ϕ_K	Modified JONSWAP shape function in finite water
λ_o	Wavelength
$(\tilde{\zeta}_w)_{1/3}$	Significant wave height
$(\eta^2)_{1/3}$	RMS wave energy
ξ	Significant wave slope in Wallops spectrum
ω	Angular wave frequency
ω_h	Modified angular wave number in shallow water wave spectrum

ABSTRACT

Two wave measuring systems have been installed at Cape Canaveral, Florida and Kings Bay, Georgia, respectively. The technique required to continuously measure waves in a nearshore zone for a long period of time often involves problems different from those encountered when measuring in deep water. The instruments used for the systems, selection of the sites, installation and retrieval procedures, and data analysis have been reported here.

The measurement program started at Cape Canaveral and was later applied to Kings Bay. The systems were upgraded to measure directional waves in December 1983. Among the wave measuring systems, three measure directional wave spectra, mean currents and water depths. The quality of data and data recovery rate of each system at a specific site have been evaluated and reported here. Some hardware modifications have been made to ensure the operation of the instruments and to achieve a higher data recovery rate.

The measured wave data show different characteristics at each site although the same offshore storms pass through these nearshore zones. The data have been used to calibrate the shallow water wave model (SWWM), to develop a nearshore wave climatology, and to compute ship responses during navigation channel transiting.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

Wave data collected from the field are valuable in that they play an important role in the development of local wave climatologies. The field data described in this report were used to calibrate the Shallow Water Wave Model (SWWM) and to establish short-term wave statistics. These data were also used as the basis for the development of long-term wave statistics and for the validation of a nearshore wave forecast system.

Two different methods were used to collect the wave data. A system of semi-permanent wave measuring stations collecting data four times daily is used regularly. The other, a directional buoy, was deployed at a desired location for only a short period of time. All of these data eventually were stored in the data bank at

DTNSRDC. The instrumentation, sites, procedures, method of analysis, and data format will be presented in the following sections.

INSTRUMENTATION TECHNOLOGY

The technique required to continuously measure waves in shallow water for a long period of time often involves problems different from those encountered when measuring in deep water. The major differences are the water depth, shipping activities, and the rapidly changing natural environment. Along Florida's densely populated east coast, pleasure boat traffic is high and shrimp trawlers intensively work the bottom out to a water depth of 50 meters. In order to increase the data recovery rate, three different systems to measure the waves were selected.

BOTTOM MOUNTED PRESSURE TRANSDUCER

The system has been developed by the University of Florida and used extensively with the Florida Coastal Data Network.[1*] The so-called Coastal Data Network (CDN) system consists of pressure transducers for wave measurements, and a microcomputer and data communication devices to provide for the flexibility of recording serious winter storms, hurricanes and normal waves in a shallow water zone (Figure 1). One such system has been installed at Cape Canaveral in a depth of 8 meters and 2 km offshore. A cable system is used to transmit the data to the shore station and is then communicated by telephone line to a computer at the Coastal Engineering Laboratory, University of Florida, Gainesville, Florida. The system provides a near real-time wave spectrum. When a hurricane or a severe winter storm is imminent, the underwater microcomputer is instructed via telephone line to begin recording data internally. After the storm, the instrument is recovered and the data read from a digital cassette. The system installed at Cape Canaveral uses the Port Canaveral Air Force Station as a shore site (sensor A of Figure 2). The system began data collection in January 1982 and has continued to the present time. The system measures the water depth and one dimensional wave spectra. The data recovery rate has been about 70 percent for the last 3 years and is the highest when compared with the other operational systems.

Another measuring system with transducers for a different pressure range and with a different data transmitting method was also installed at Cape Canaveral.

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*A complete listing of references is given on page 17.

The system was located about 17 km offshore in a water depth of 15.5 m (sensor B of Figure 2). Because of the long distance from shore, data communications through a cable system was impractical. A radio telemetry link was established between a buoy and the shore station.

A moored surface buoy becomes especially vulnerable in rough seas when shrimp boats or pleasure craft are searching for a sheltered area. Consequently, the buoy was involved in collisions several times and the subsurface instruments were dragged upon occasion. The system was frequently nonoperating and provided data only for a short period after it was installed. The data recovery rate was less than 10 percent. After careful evaluation of the data output and method of deployment, the instrument package was changed to a submersible system described in the following section.

BIAXIAL CURRENT METER/PRESSURE GAUGE COMBINATION

This system is the primary wave sensor presently used at both Kings Bay and Cape Canaveral (see sensor B of Figure 2 and stations 4 and 5 of Figure 3). This is a self contained wave measuring sensor with the ability to measure two axis water velocities, U and V, magnetic direction of U and V, water depth, and ocean wave profile by pressure transducer. The sealed container, referred to as the PUV package, also includes a microcomputer and magnetic digital tape which is capable of operating continuously for 3 to 4 months (Figure 4). The unit, which is manufactured by Sea Data, Inc. (Model 635-12), can operate at a water depth up to 100 meters. The system not only provides directional wave spectra but also mean current and water depth information.[2,3]

Two semi-permanent stations were installed in the Kings Bay area in November 1983, as well as the one previously mentioned in deep water at Cape Canaveral in May 1984. The University of Florida (UF) at Gainesville, Florida was responsible, under contract to DTNSRDC, for the installation, maintenance, data collection and analysis. The UF team retrieved the instrument package, changed the digital tape and checked the system before reinstallation every 2 to 3 months on a routine basis.

The data recovery rates of the systems were good during the early stage of operation. However, after continuously operating for a year, one system located near the channel entrance at Kings Bay in the heavy shrimping zone was reported missing. The other two systems were also snagged and were in the shop for repair for a short time before they were reinstalled. The overall data recovery rate for

the first year was about 60 percent at Kings Bay and 65 percent for the Cape. The detailed locations and the period of data collection are listed in Table 1 and shown in Figures 2 and 3.

The nearshore pressure transducer and the PUV packages are mounted on tripods which are fixed in place with jetted pipes (Figure 5). The pressure transducer is mounted inside of the tripod and about 1 meter off the seabed, while the current meter is mounted outside the tripod and about 1.6 meters off the seabed. Although the edges of the tripods were smoothed to avoid the snagging of fishing nets, accidents still occurred. Recently, the mounting frame of the offshore station at the Cape was changed to a dome shape (Figure 6), to reduce damage by fishing boats. The mounting frames at the Kings Bay area are in the process of being converted to the dome shape.

ENDECO WAVE TRACK BUOY

A field experiment was conducted to investigate the variation of directional waves along the entrance channel of Cape Canaveral. Two ENDECO wave-track buoys were deployed.[2] Four weeks of directional wave data were collected during the experiment. The data from these buoys and from the fixed UF stations provided a complete description of wave climate for this period. These data sets were used to calibrate the Shallow Water Wave Model (SWWM) and for ship seakeeping trial support.

The ENDECO buoy has been termed an orbital following buoy since the buoy responds (tilts) to the orbital particle motion of the waves. The buoy motion differs from the more conventional slope following directional buoys, although the data analysis is handled in much the same fashion.[4] The buoy contains a pitch-roll sensor, flux-gate compass, and an accelerometer (see Figure 7). Signals from the buoys were telemetered to nearby boats and recorded on a digital computer, an analog tape recorder, and a strip chart recorder. A Digital Equipment Corporation microcomputer was used to analyze the data. In rough seas, the data transmissions were sometimes interrupted by wave shadowing effects between antennas and receivers, or by plunging of the antenna caused by breaking waves.

Four deployment locations were selected for the ENDECO buoys as shown in Figure 2 and Table 2. Table 2 also specifies the water depth, number of data sets collected and dates of deployment for the respective locations. Data were collected from the buoys for only a relatively short period of time as indicated.

DATA PROCESSING

The data processing of the measurements obtained from the four fixed semi-permanent systems was performed by the University of Florida (UF). They conduct the following data processing related functions:

(1) Access raw data record - digitize time series data.

(2) Search the time series data for identifiable bad data caused by data transmission or recording interference; a UF program performs both diagnostic checks to identify bad data and editing to correct errors where possible.

(3) Filter the data to establish the zero-mean of the record.

(4) Perform Fast Fourier Transformation (FFT) to determine Fourier coefficients and to construct the energy spectrum or the directional wave spectrum.

(5) Provide other statistical analyses to obtain such information as significant wave height, modal wave period, mean wave direction, current strength, and direction.

(6) Archive data files and provide direct access for DTNSRDC through telephone lines.

(7) Produce a monthly data report and yearly summary reports.

These functions are described in detail in Users Guide of Data Processing Software Package by UF (1984).[5]

The data processing of the ENDECO Wave-Track buoy has been described in a recently published report.[6] The data was also edited and filtered, when necessary, prior to using an FFT program. The output format from buoy measurements differs from that given by UF for the submersible PUV system. Several directional wave spectral formats are available from buoy analysis. Some of these will be discussed in the following sections.

DATA FORMATTING AND FILING

CAPE CANAVERAL

Nearshore Station

This station provides water depth, significant wave height, modal period, and percent energy in wave period bands. The sampling rate used at the nearshore station is one sample per second with a total data length of 17 minutes. A bandwidth of 1/64 Hz is used to compute the point spectrum. This is the only station that

provides near-real time point spectra. A DTNSRDC minicomputer is connected to UF via telephone lines and is provided with up to 3 days of the latest wave data. A sample of the data is shown in Table 3a. The computer output can also be shown in the spectral format such as Figure 8, where wave energy is expressed as a variance spectrum. Every month the data are collected and sent to DTNSRDC in an informal report. A sample of this report is shown in Table 3b.

Offshore Station

Only a limited amount of data were collected at the offshore station prior to the 1983 sensor change to the PUV system. The original sensor and analysis procedure used for this station are the same as the nearshore station. Some samples of these measurements are shown in Figures 9a and 9b for simultaneous measurements at both stations. The data were obtained during the passage of a north-eastern storm during September 1983. All the wave spectra shown are one dimensional spectra. The early stages of the storm are shown in Figure 9a. The figure shows that the effect of bottom topography is overpowered by the storm force. The shape and total wave energy are almost the same for both stations. However, when the storm is over, the effect of bottom topography becomes a dominant factor as shown in Figure 9b. The wave spectrum at the nearshore station decreases drastically. The results from this figure imply the existence of another important physical parameter, i.e., the approaching wave direction and the wave stage of the storm. The effects of approaching wave angle have been clearly demonstrated in another report.*

The PUV sensor was used to measure the directional wave spectrum after 1984 and the analysis is based on the method proposed by Longuet-Higgins et al.[7] The directional wave spectrum, $E(f,\theta)$, is expressed as

$$E(f,\theta) = S(f) \cdot H(f,\theta) \tag{1}$$

where f is wave frequency, θ is approaching wave direction, $S(f)$ is one dimensional wave spectrum, and $H(f,\theta)$ is a directional spreading function with

$$\int_0^{2\pi} H(f,\theta)d\theta = 1 \tag{2}$$

*Lai, R.J. and A.L. Silver, "Shallow Water Wave Model (SWWM) at Cape Canaveral, Florida and Kings Bay, Georgia," Report DTNSRDC/SPD-1190-01 (Jun 1986) (limited distribution report, not available to the public).

for each frequency band. The spreading function is given by a truncated Fourier component as[6,7]

$$H(f,\theta) = \frac{1}{\pi} \left[\frac{1}{2} + \sum_{n=1}^{2} W_n(a_n \cos n\theta + b_n \sin n\theta)\right] \qquad (3)$$

where W_n is a weighting parameter, a_n and b_n are the Fourier coefficients in the expansion of $H(f,\theta)$.

The values of a_n and b_n are determined from the auto and cross spectral analysis using P, U, and V where P is the measured pressure caused by the variation of surface elevation, U and V are the water particle velocities in the horizontal plane induced by the wave.[8,9] Furthermore, the spreading function is simplified and expressed as[10,11]

$$H(f,\theta) = \frac{1}{\pi} \left[\frac{1}{2} + \sum_{n=1}^{2} R_n \cos n(\theta - \theta_n)\right] \qquad (4)$$

where $$R_n = \pi[a_n^2 + b_n^2]^{1/2} \qquad (4a)$$

and $$\theta_n = \frac{1}{n} \tan^{-1} (b_n/a_n) \qquad (4b)$$

The values of θ_1 and θ_2 are the mean wave direction from the first and second harmonic, respectively. The rms spreading angle, θ^*, is calculated from

$$\theta^* = R_1/(1-R_1) \qquad (5)$$

A sample of directional spectra is shown in Figures 10a and 10b and the data format is given in Table 4. One energy spectrum is computed from the pressure transducer and the other is computed from the transformation of wave particle velocities. Both curves seem to agree well in the low frequency range but show discrepancies in the high frequency range. The current sensors seem to pick up some extra energy in the higher frequency range. Only the values obtained from the pressure transducer were selected for further use. Based on the calibration curves

and the effects of water depth where the sensors operated, the cut-off frequency was set at 0.25 Hz throughout the analysis. The units of data in Table 4 are m^2-sec for wave energy, E, and the mean angles, θ, are corrected to be oriented with respect to the true North. The values of R_1 and R_2 correspond to parameters of equation (4).

A sample of the monthly report is shown in Table 5. Here all the statistical values, such as significant wave height, $(\bar{\zeta}_w)_{1/3}$, and modal frequency, f_o, wave direction, θ_1, rms spreading, θ^*, mean current amplitude and direction and water depth are listed for the entire operational period during that month.

KINGS BAY

The two measuring stations at Kings Bay both use PUV sensors. These stations were installed in December 1983. The data format is the same as the offshore station at Cape Canaveral as discussed previously. The data were collected every two to three months during 1984. Samples of these measurements are shown in Figures 11a and 11b and in Table 6. During the summer and fall seasons of 1984, hurricanes hit the southeast coast of the United States. The two stations collected a series of directional wave data and corresponding storm surge data. After the data were retrieved, it was found that only offshore station Number 5 functioned properly. This points out a deficiency of the submersible system. A failure of the system cannot be detected until retrieved at a later date.

Two hurricanes and a Northeast storm that hit the southeast coast were evident from review of the September 1984 data. The hurricanes were generated from the south and the Gulf of Mexico and headed north along the coast after missing the Florida peninsula. The strong winds did not have sufficient fetch to generate long, high waves. However, the local generated wind waves accompanied with storm surge induced a great amount of beach erosion. The time series of measured winds, significant waves, currents, and water depths are shown in Figure 12 during the month of September. Most waves were from the northeast, east and southeast directions as shown in this figure. The direction and amplitudes of currents were different from the waves and winds. During the passage of the storms, the currents moved against the predominate wind directions. The wind data shown here were obtained from the NOAA buoy No. 4.[2] Further analysis of the correlation of directional waves and wind will be given later.

DISCUSSION OF RESULTS

CORRELATION OF LOCAL WIND AND WAVE

Wind has always been considered an important source of wave energy and an indicator of the severeness of a storm, as is also shown in Reference 2. Three different sources of measured wind data were available for consideration. A NOAA buoy located outside the eastern edge of the Gulf Stream, about 185 nautical miles southeast of Kings Bay and 135 nautical miles east-northeast of Cape Canaveral, provides wave heights and periods, as well as wind speeds (U_o) and directions. Local wind speed (U_n) and direction are also measured at the meteorological stations at the Mayport Naval Air Base for Kings Bay and at the Cape Canaveral Air Force Station for Cape Canaveral. These wind data were carefully evaluated and correlated to the measured wave data.

Strong winds imply high seas in deep water. In the nearshore zone, however, winds come from all directions and waves are limited to onshore directions; therefore, the correlation of local wind and waves becomes a difficult task. Measurements of wind and waves at Kings Bay provide both amplitudes and directions. Based on these data, wind and wave roses for the winter season of 1984 are computed and shown in Figures 13 and 14. Although most of the winds of the shore station are from west, north, and northeast directions, the approaching wave angles are confined by geography to northeast, east, and southeast directions. Similar comparisons are shown in Figures 15 and 16 for the summer of 1984. There exists some correlation; however, a precise local correlation is almost impossible to establish. This points out the fact that the wave climate in the nearshore zone is dominated by the storm and wind patterns offshore and propagates to the shore with some local wind input unless the onshore storm persists for more than 24 hours. At that time, the local wind and wave direction coincide, as shown in Figure 17.

The time series of measured wind and waves shown in Figures 12 and 17 further illustrate the relationship of wind and waves in the nearshore zone. The data in Figure 12 show the relation between local waves, $(\zeta_w)_{1/3}$, current, U_w, and tidal level, h, with nearshore wind, U_n, during the hurricane season. There is some correlation between nearshore wind and local waves during the arrival of the hurricanes and storms. Other than that, the correlation is poor. In Figure 17, time series of local waves and offshore and nearshore winds are presented, enabling a correlation between them to be shown. These data are part of the measurements

taken during the 1984 winter season. The nearshore wind (U_n) is always smaller than the offshore wind (U_o). Wind direction consistently correlates with the cyclic motion of the winter storm. The storm starts with the wind blowing from southeast direction, rotating clockwise to south, southwest, west, northwest, and north directions, and ends at the northeast and east directions. At the same time, the nearshore wave directions also start from the southeast direction and rotate counterclockwise to the east and northeast directions. Although the wind and wave directions coincide at the beginning and at the end of the storm, they oppose each other during the storm passage. The scale and the characteristics of storms can also modify the wave direction in the offshore zone and consequently the wave direction in the nearshore zone. Except for the storm data, the evidence for correlation of wind direction between nearshore and offshore zones is skimpy. Although some correlation exists between offshore wind and nearshore wave directions, the correlation between nearshore wind and wave direction is poor.

DATA RECOVERY RATE

A high data recovery rate is desirable but not easily obtained for a wave instrument package operating in a harsh nearshore environment. The reliability of the instruments, the life span of the instruments, location of the installation, and the severity of the storms all contribute to the data recovery rate. During the past three years, the instrument packages have been changed to directional wave sensors due to operational requirements. The frames of the submersible instrument package were converted from a tripod to a dome shape and the site of the locations has been moved to different locations after each accident. The data recovery rate has been maintained at 50 percent. Recently, all the instruments seem to be operating inconsistently. This may be related to the actual life span of the sensors for continuous operations in a marine environment. A thorough laboratory check out, inspection and calibration of the field instruments has become necessary every 2-3 months during the retrieval of recorded data. This precaution will reduce the chance of instrument breakdown and increase the data recovery rate.

MEASURED DIRECTIONAL WAVE SPECTRA CHARACTERISTICS

According to the measured wave data and forecast/hindcast statistical wave data from the Spectral Ocean Wave Model (SOWM), which have been discussed in another report, rough seas tend to occur in the fall and the winter seasons. As

winter storms approach from the north and the northeast directions, high sea states persist in the nearshore zone. The changes of major wave characteristics are closely related to the stage of the storm. These will be shown and discussed from the series of measured directional wave spectra in the following sections.

Cape Canaveral

Two series of measured wave energy spectra at stations 1 and 2 are shown in Figures 18 and 19. The wave spectra at the early stage of the storm are shown in Figures 18a and 19a. The spectrum of wind waves with f_o of 0.133 Hz shows the arrival of the storm (Figure 18a) where f_o is the primary modal wave frequency. As the wave trains moved shoreward, the long waves were attenuated but the short waves gained strength (Figure 19a) which indicated the effects of bottom friction and the continuous input of the local wind force.

When the storm reached full strength, the wave spectra showed multiple peaks at both stations (Figures 18b and 19b). The bimodal wave spectrum was evident at station 2, but was not so clear at station 1. Actually, these two spectra were not measured simultaneously. A 4-hour time lag between measurements may have allowed waves to modify significantly.

When the storm was over, the wave spectra were dominated by the long swell accompanied by the local wind waves. The swell was attenuated by the bottom friction and local shaoling zone as the waves approached the shore (Figures 18c and 19d). In fact, all wave spectra showed strong bimodal wave characteristics, especially at station 1 (the opposite was true at the peak of the storm). It is interesting to point out that secondary peaks measured in the bimodal spectra did not coincide with the higher harmonic frequency of the major peak in the spectrum. This indicates that the strong nonlinear characteristics in finite water depth did not dominate the high frequency waves which were generated by local wind.

The corresponding mean directions of measured waves are shown as the dotted lines of Figures 18 and 19 for stations 1 and 2. At the early and middle stages of the storm, the variation of wave directions among primary and secondary waves are small, and all followed the wind direction closely. The wind and wave directions both started from 70 degrees north and slowly changed to 30 degrees north. The differences between wind and wave directions are less than 30 degrees. However, the wave directions showed a drastic change at the end of the storm, as in Figures 19c and 19d. The local wind shifted quickly to the north and northwest in shallow

water. The wind and wave directions were no longer collimated. The local shoaling and finite water depth became the dominate factor. The higher frequency wind waves tended to follow the local wind direction. The direction of swell shifted from the northeast to a northwest direction. The reason for the change of swell direction after the entering the shoaling zone is not clear. It may be caused by the reflection of waves, trap wave phenomena, the ambiguity of the measuring buoy in this environment, or any combination.

Kings Bay

Another series of measured wave energy spectra at stations 4 and 5 during the winter storm are shown in Figures 20 and 21. During the early stage of the storm both wave spectra show multiple peaks. The peak frequencies shifted from the high end to the low end as the storm developed. At the decay stage of the storm, swell seems to dominate in the spectral energy distribution. Although primary peaks exist for all spectra at different stages of the storm, a large portion of the wave energy is still contained in the high frequency domain. This suggests that wave spectra in the nearshore zone always are in the transient stage.

The corresponding wave direction of these wave spectra are shown in the dotted lines of Figures 20 and 21. All the wave directions are clearly divided into two groups, long and short wave groups. The long wave groups refers to waves with frequency less than or equal to 0.14 Hz and the short waves have frequencies larger than 0.14 Hz. The directions of long waves are confined between 70 to 110 degrees, while the short waves varied from 0 to 60 degrees. This phenomenom indicates that the long waves are generated from the offshore zone eastward of the Gulf Stream. After crossing the Gulf Stream, they follow ray theory and refract and converge to the eastward direction. The short waves are generated by the local wind and follow the local wind direction closely. Details of the effects of the Gulf Stream and land on wave climatology will be given in another report.

SIMILARITY OF THE WAVE SPECTRUM IN SHALLOW WATER

Surface waves in a shallow water zone are always in a transition stage. The waves are continuously modified by the local and nearby bottom bathymetry and other nearshore dynamic parameters. To find similarity between sets of shallow water wave spectra is a difficult task. Recently several papers have been published to

develop a function to describe the shallow wave spectrum.[12,13,14] Some of the results have been applied here to compare with the measured data.

The JONSWAP spectrum in deep water is expressed as[14]

$$E_J(f) = E_P(f)\,\phi_{PM}(f/f_o)\;\phi_J(\gamma,\sigma,f,f_o) \tag{6}$$

with

$$E_P(f) = \alpha g^2\,(2\pi)^{-4} f^{-5} \tag{7}$$

$$\phi_{PM}(f/f_o) = \exp -1.25(f/f_o)^{-4} \tag{8}$$

$$\phi_J(\gamma,\sigma,f,f_o) = \exp\left[\ell n(\gamma)\exp(-(f/f_o)^2/2\sigma^2 f_o{}^2)\right] \tag{9}$$

where E_P is the Phillips equilibrium range spectrum with a variable α, ϕ_{PM} is the shape function by Pierson and Moskowitz and ϕ_J is the JONSWAP shape function, and where f_o if spectral peak frequency, γ is the peak enhancement factor and

$$\sigma = 0.09 \text{ for } f_o < f$$

$$\sigma = 0.07 \text{ for } f_o \geq f$$

The JONSWAP spectrum has been translated to shallow water and expressed as

$$E_s(f,h) = E_J(f)\;\phi_K(\omega_h) \tag{10}$$

where

$$\phi_K(\omega_h) = \left[\{K(\omega,h)\}^{-3}\,\frac{\partial K(\omega,h)}{\partial f}\right] / \left[\{K(\omega,\infty)\}^{-3}\,\frac{\partial K(\omega,\infty)}{\partial f}\right] \tag{11}$$

and

$$\omega_h = 2\pi f\,(h/g)^{1/2}$$

and where K is wave number, ω is angular wave frequency and h is water depth.[14]

The Wallops spectrum has been derived and expressed as[12]

$$E_W(f,h) = \beta g^2 f_o{}^{-5}\left(\frac{f_o}{f}\right)^m \exp\left[-\frac{m}{4}\left(\frac{f_o}{f}\right)^4\right] \tag{12}$$

and $$m = \left| \ln\{2\pi^2\ \xi^2 \coth^3 K_o h[1 + \{3/(2 \sinh^2 K_o h)\}]^2\}/\ln 2 \right| \tag{13}$$

$$\beta = (2\pi\xi)^2 m^{(m-1)/4} \tanh^2 K_o h/4^{(m-1)/5} \cdot \Gamma[(m-1)/4] \tag{14}$$

where Γ is a gamma function, ξ is the significant shape defined as

$$\xi = (\eta^2)^{1/2}/\lambda_o$$

and where $(\eta^2)^{1/2}$ is the rms wave energy and λ_o is the wavelength of the waves at the spectral peak.

Two sets of measured data and the corresponding proposed wave spectral model are shown in Figures 22 and 23. Measured wave data during the northeasterly storms at Cape Canaveral and Kings Bay are shown in Figures 22a and 22b respectively. In these figures, the solid lines represent the measured data, the dashed lines the JONSWAP spectra in deep water, the dotted lines the modified JONSWAP spectra in finite water, and the dash-dotted lines the Wallops spectra in finite water. The measured spectra consist of multi-peaks over a broad band of energy. It is obvious that none of the wave models compare well to the measured data, since all of these models are developed by assuming that the wave spectrum is narrow and single peaked. If multiple peaks exist, the superposition of several submodels could be used to represent the spectrum.[15]

The spectra dominated by swell at Cape Canaveral and Kings Bay are shown in Figures 23a and 23b. The agreements between wave model and measured data are better although the energy distributions around the peak frequency show some deviations. Furthermore, the energy distributions at the high frequency region are also different. All of these deviations suggest the effects of local wind and current, and bottom bathymetry in the vicinity of the measuring sites. Modification of the spectra by water depth alone is not enough to account for the overall changes that occur in the nearshore zone.

APPLICATIONS OF THE MEASURED DATA

The measured data have been used to calibrate the DTNSRDC Shallow Water Wave Model (SWWM). The data have also been used to develop short-term and long-term wave statistics which will be described a later report. The data can also be used

to combine with the U.S. Navy Global Spectral Ocean Wave Model (GSOWM) forecast/ hindcast system to develop a local directional wave forecast. The approach will be the subject of a later report. Another application is to investigate the wave directional spreading in the nearshore zone from the measured directional wave spectra. Directional spreading tends to form a series of short-crested waves critical to the computation of ship motions and grounding analysis.

CONCLUDING REMARKS

Setting up field measuring stations to collect wave data was a necessary step to develop a shallow water wave transformation model and local wave climate. As shown by measured data, the correlation between local winds and waves is poor except in the presence of persistent northeast storms. The local wave climate has been developed by using the accumulated measured data and relating it to the offshore hindcast wave data.

Reliability of the instruments and the avoidance of snagging in fishing nets were the two major problems affecting data recovery rate in the nearshore zone. Several precautionary steps and modifications of the instrument support have been made to avoid damage and to increase the data recovery rate. For future application, either a land based remote sensing technique or a permanent structure for instrument housing are recommended.

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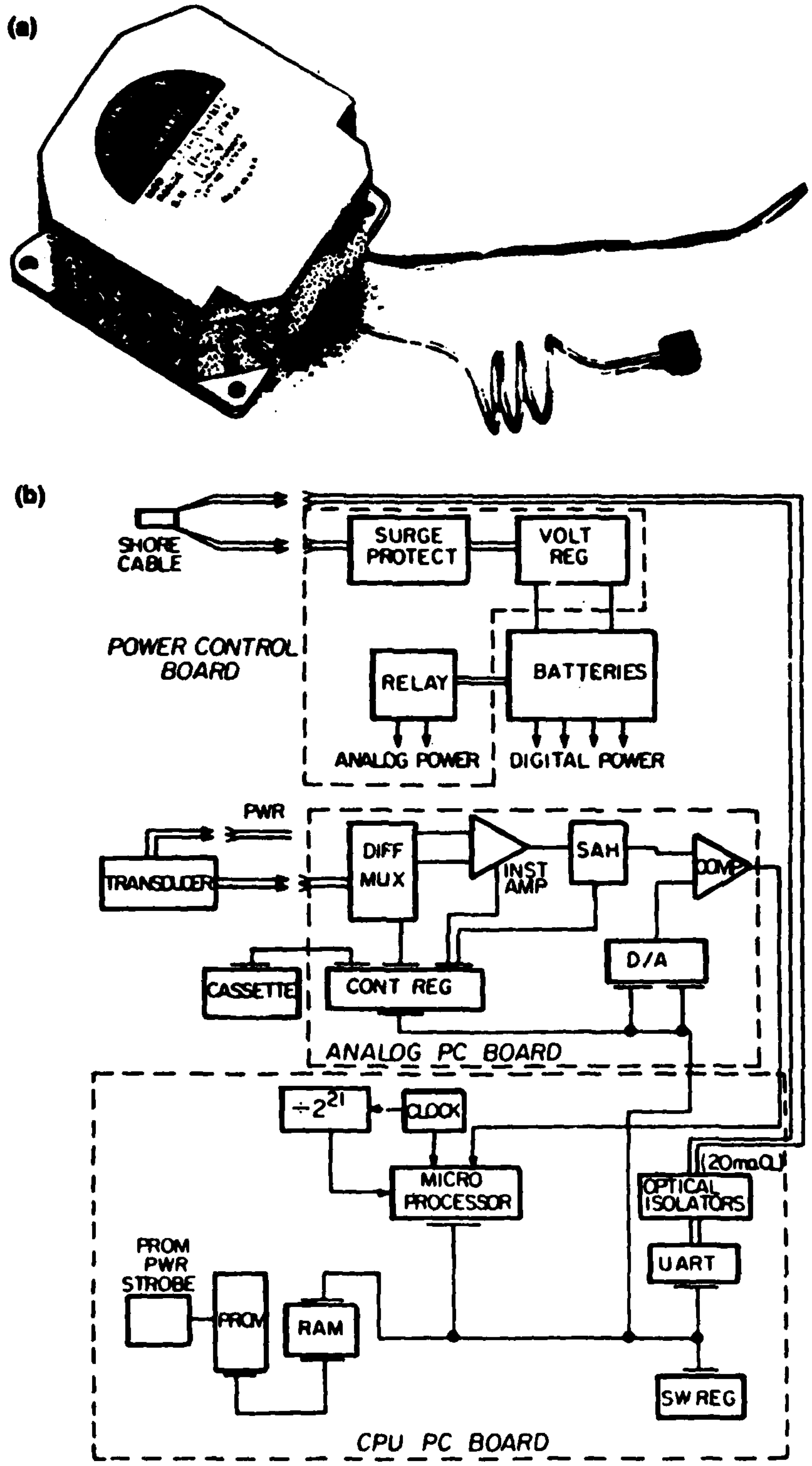

Figure 1 - Wave Measuring System, (a) Pressure Transducer, (b) Block Diagrams of Underwater Data Acquisition System

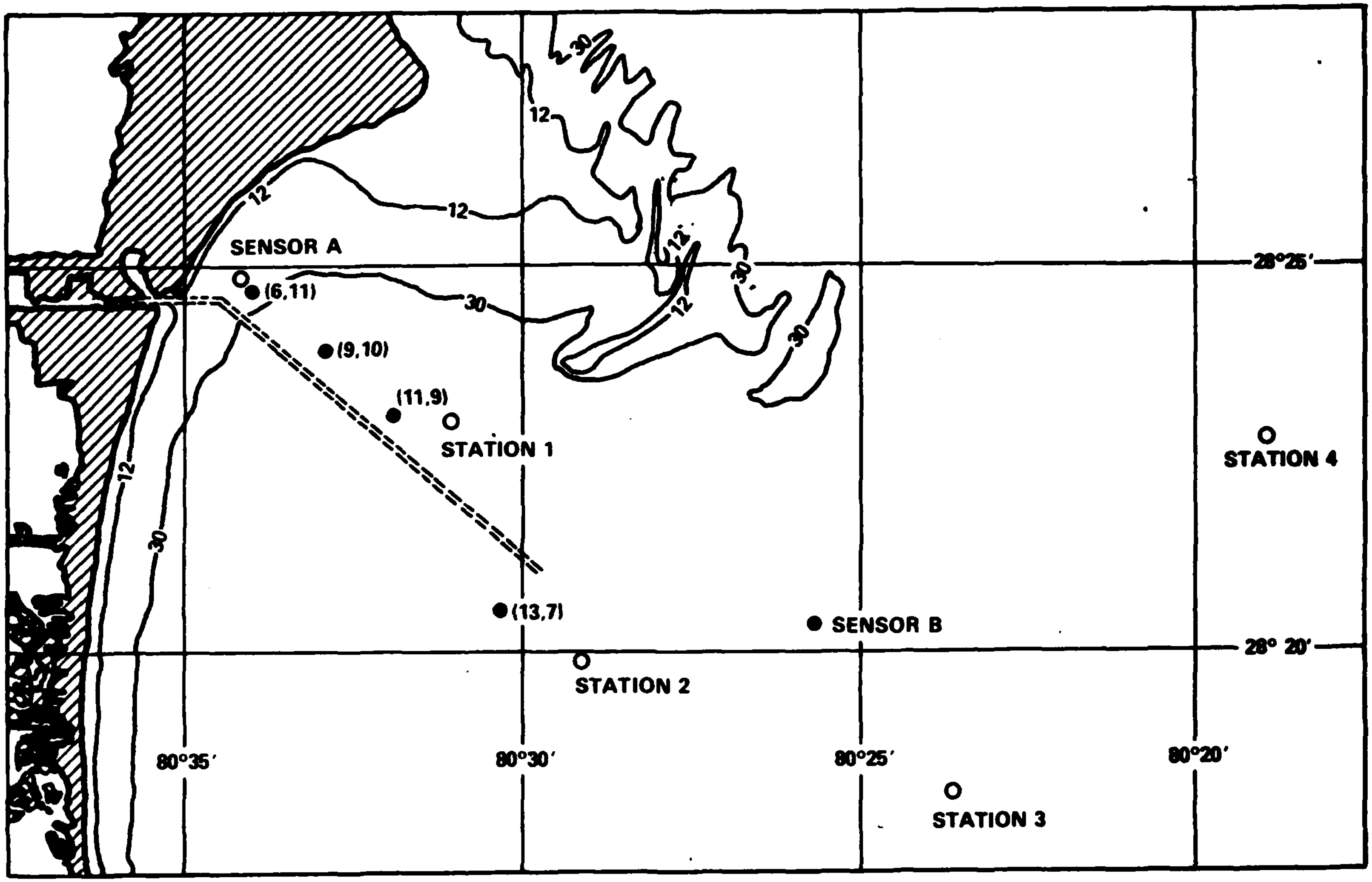

Figure 2 - Location of the Wave Measuring Sites at Cape Canaveral, Florida. Sensors A and B are Semi-Permanent Stations and Stations 1-4 are Buoy Locations During Trials

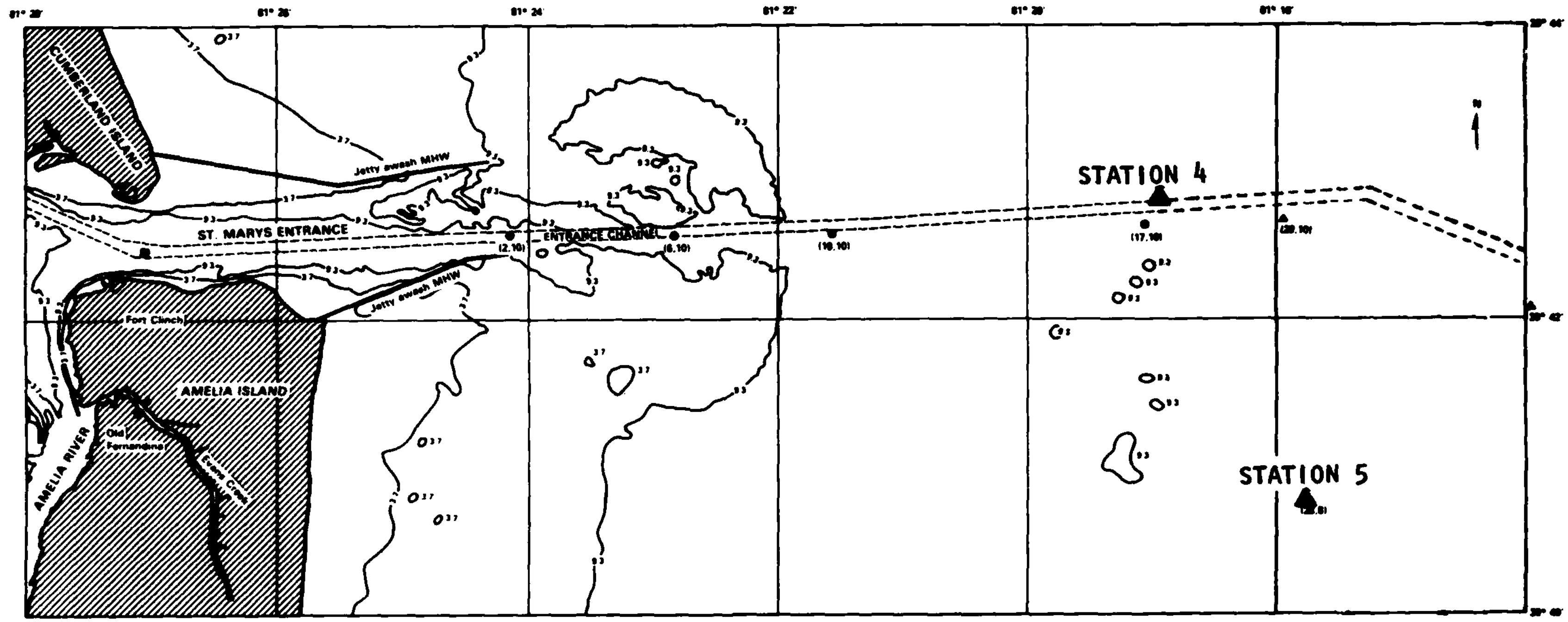

Figure 3 - Location of the Wave Measuring Sites at Kings Bay, Georgia

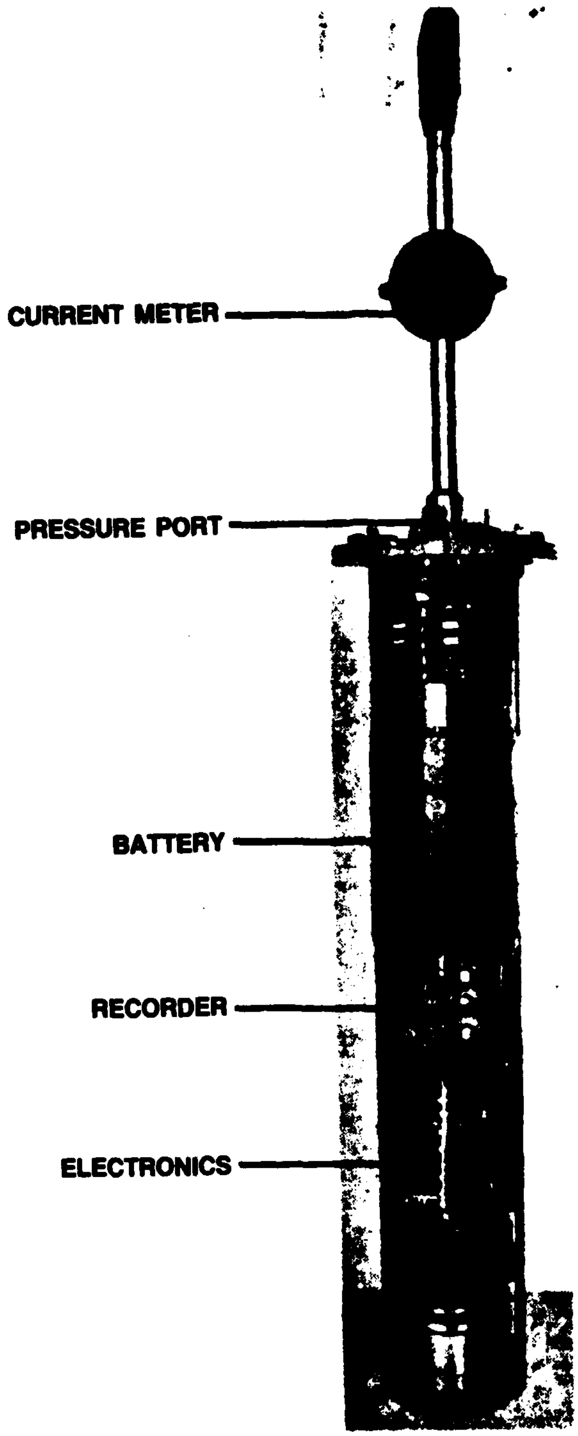

Figure 4 - The Sea Data PUV Instrument Package

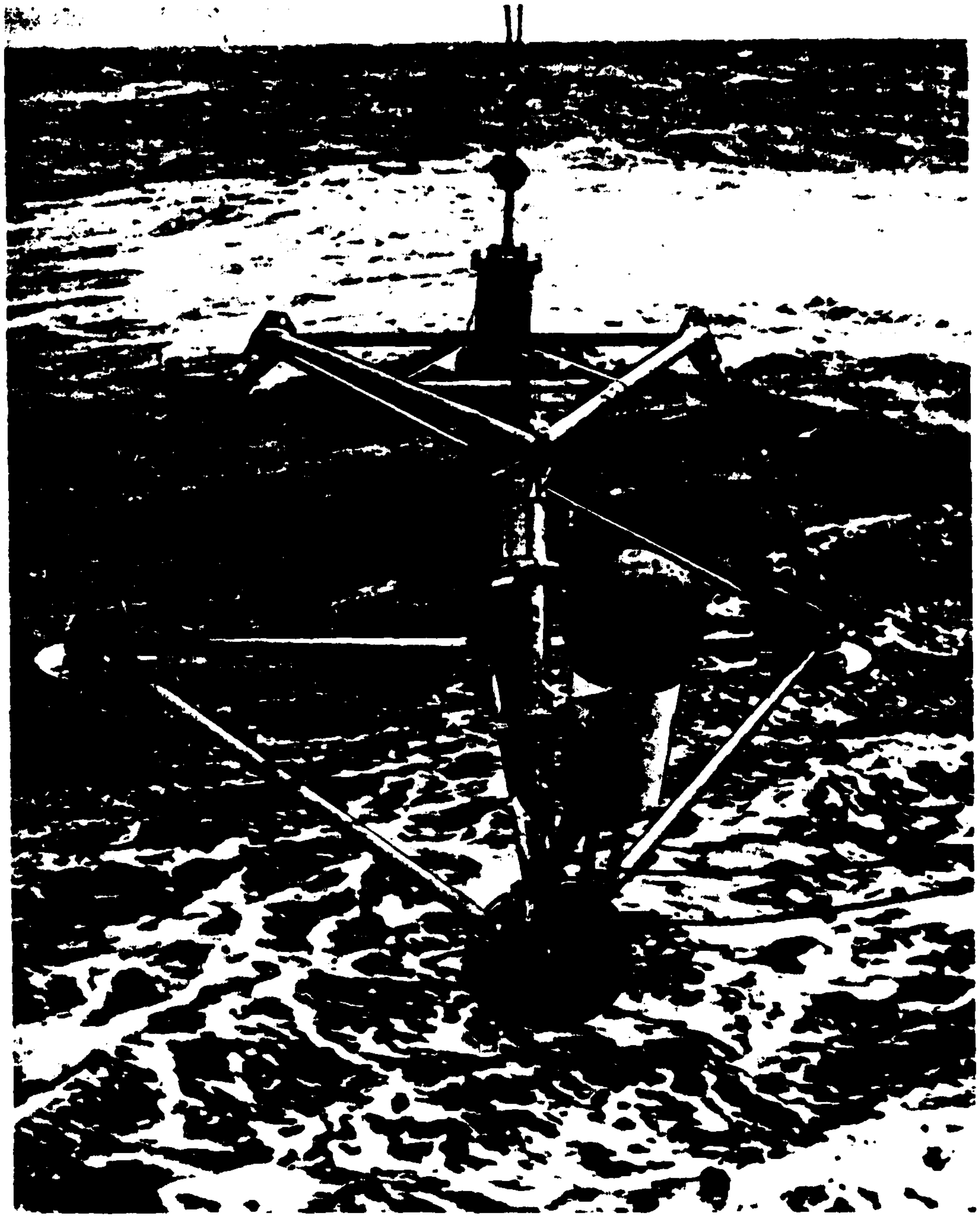

Figure 5 - PUV Package and Its Supporting Structure

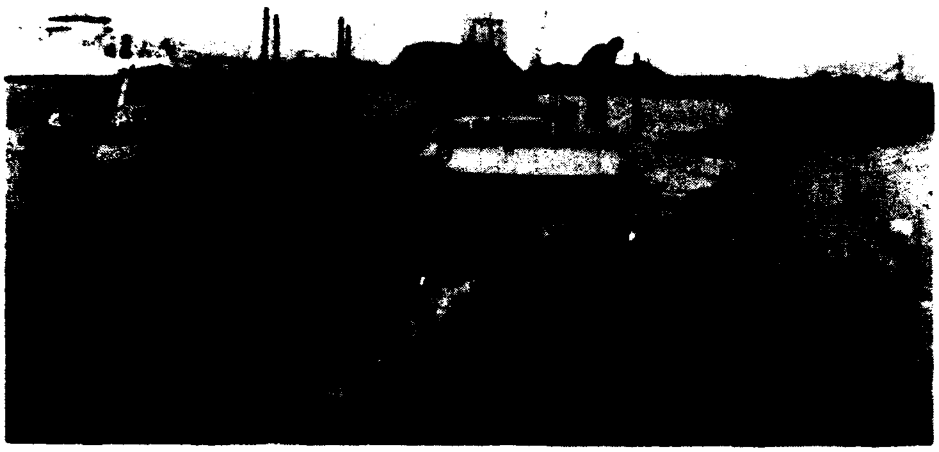

Figure 6 - Modified Dome Shape Instrument Mounting Structure

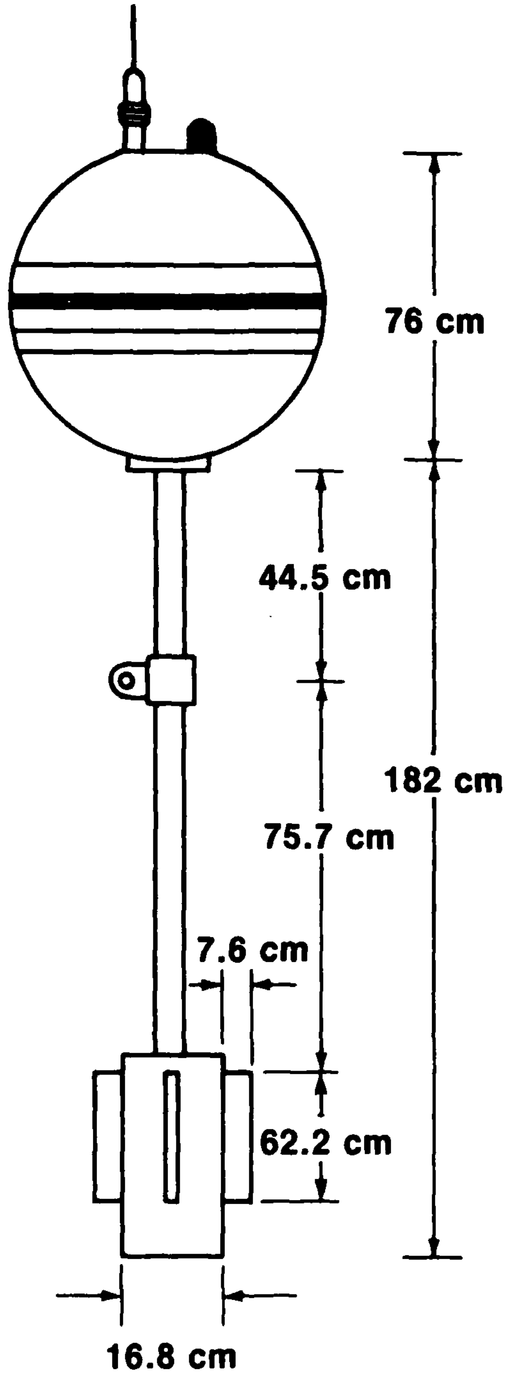

Figure 7 - Dimensions of Endeco Buoy

COASTAL DATA NETWORK

UNIVERSITY OF FLORIDA. GAINESVILLE. FL. 01-MAR-83

WAVE DATA ANALYSIS REPORT FORMAT B VERSION 3.2

POWER SPECTRUM

FILENAME	STATION	JULIAN DAY	YEAR	LOCAL TIME
COCT82	CAPE KENNEDY	285	1982	12:20

TIME SERIES STATISTICS (CM)

AVG	MIN	MAX	RMS
824.356	754.807	902.452	104.821

SPECTRAL STATISTICS CORRECTED TO WATER DEPTH

MEAN (CM)	TOTAL ENERGY (CM-CM)	S.D. (M)
824.356	1268.445	35.615

SPECTRAL PEAK (HZ)	SWH (CM)
0.063	142.461

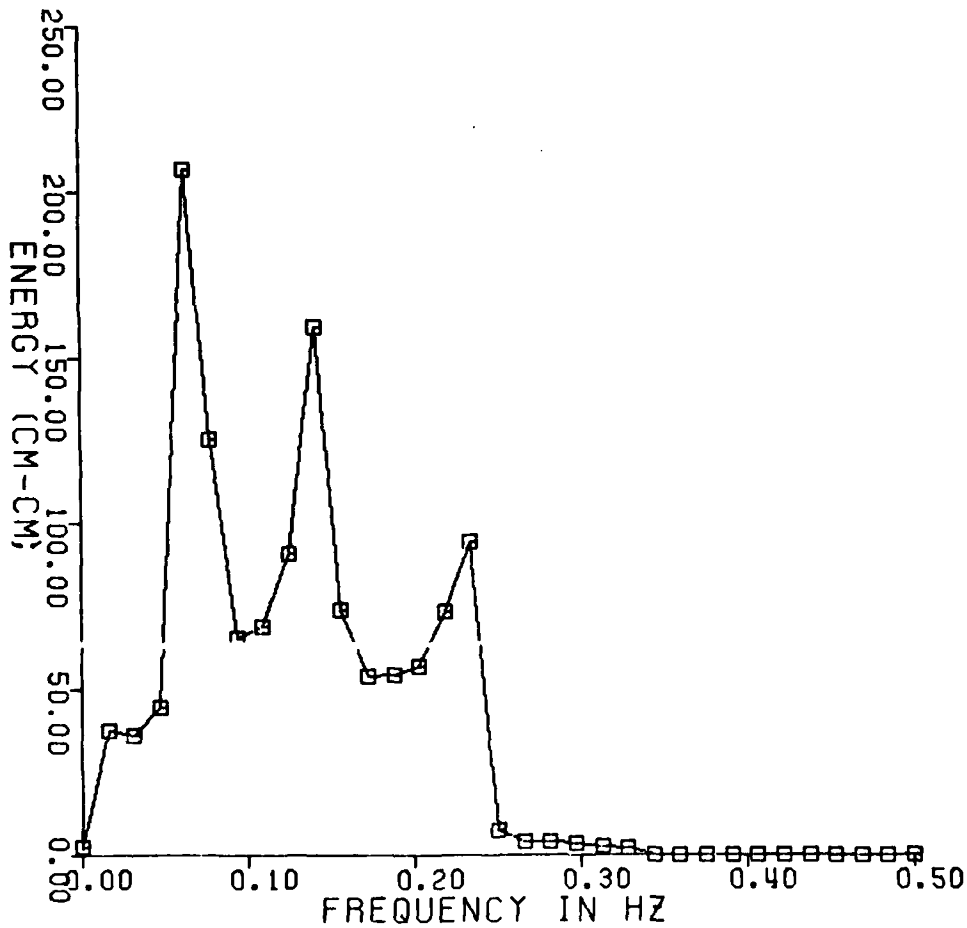

Figure 8 - Sample of Measured Wave Spectrum at the Nearshore Station of Cape Canaveral, Florida

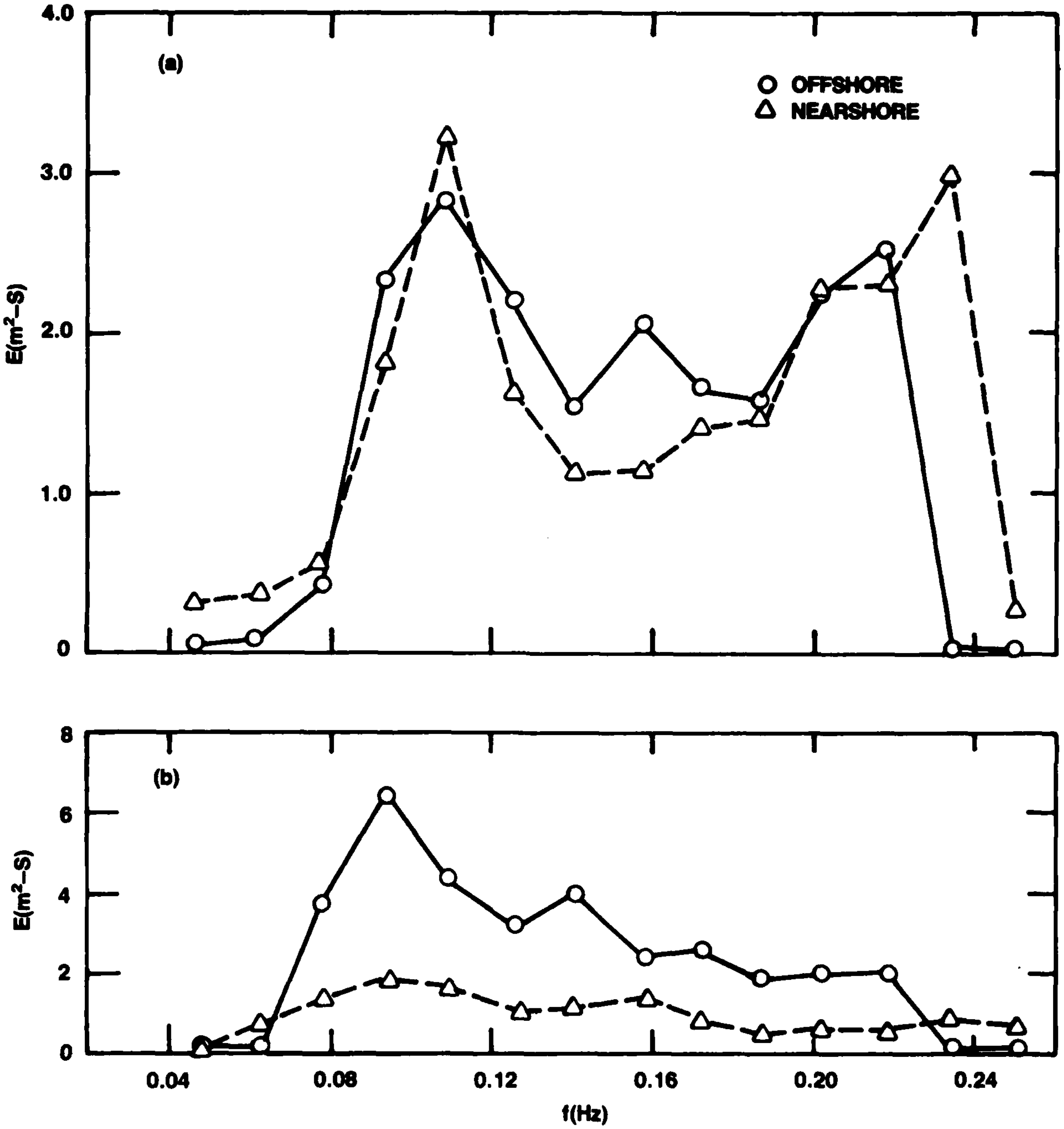

Figure 9 - Simultaneous Measured Offshore and Nearshore Spectra at Cape Canaveral in Storm Wind Sea (a) and Swell Sea (b)

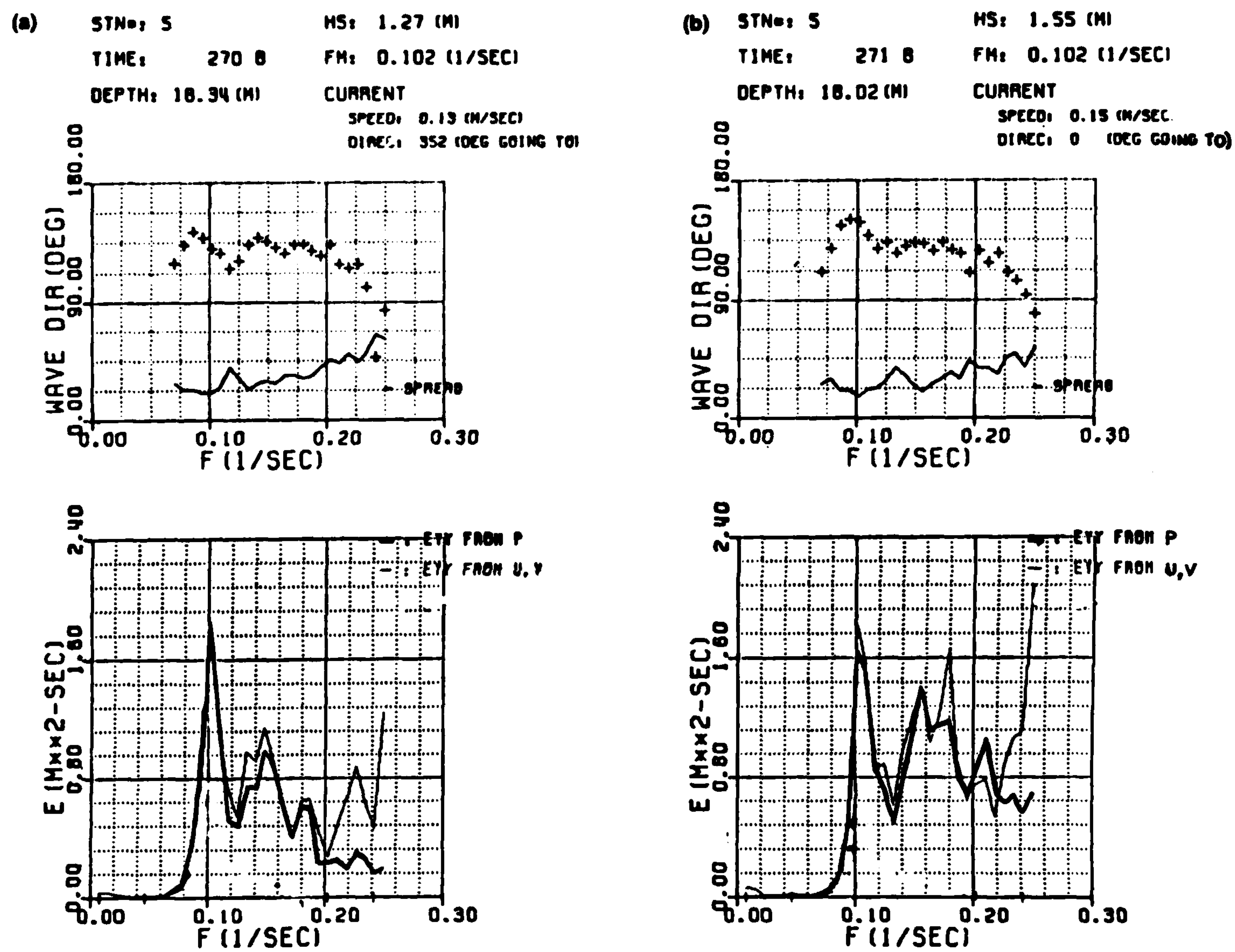

Figure 10 - Sample of Measured Directional Wave Spectra at Kings Bay, Georgia

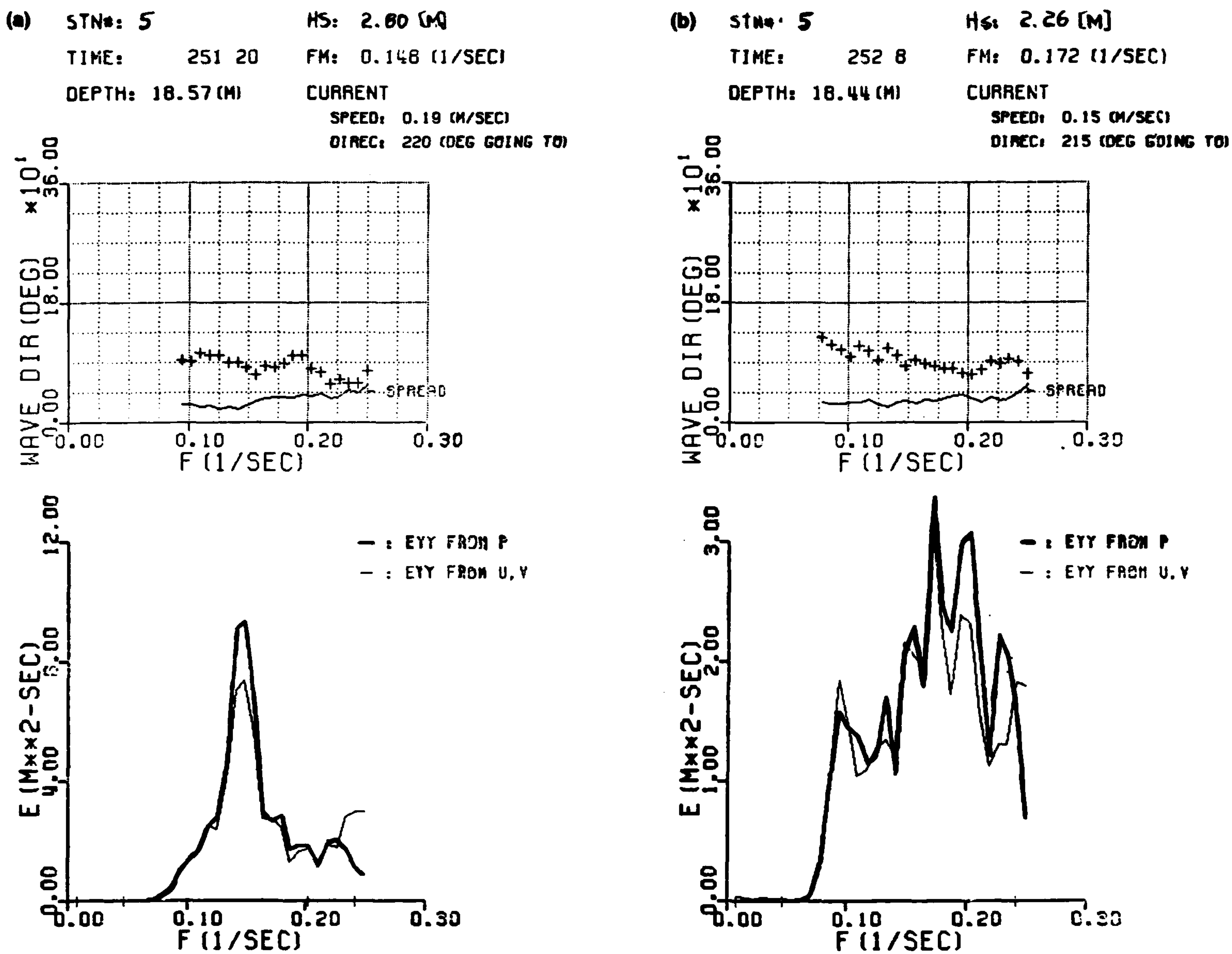

Figure 11 - Measured Hurricane Wave Spectra at Kings Bay

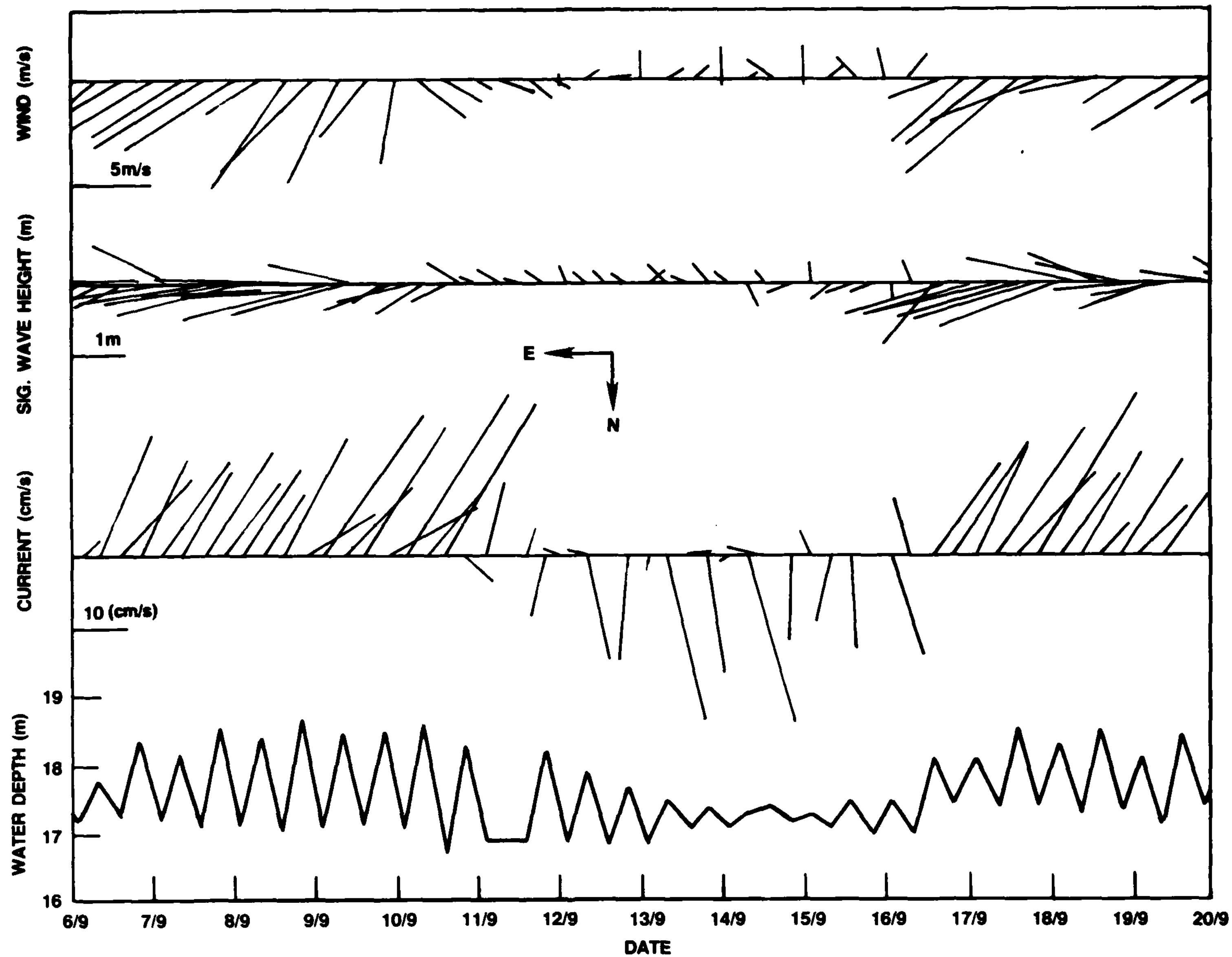

Figure 12 - Measured Wave, Current and Water Depth at Station 5 of Kings Bay and Local Wind Speed during September 1984

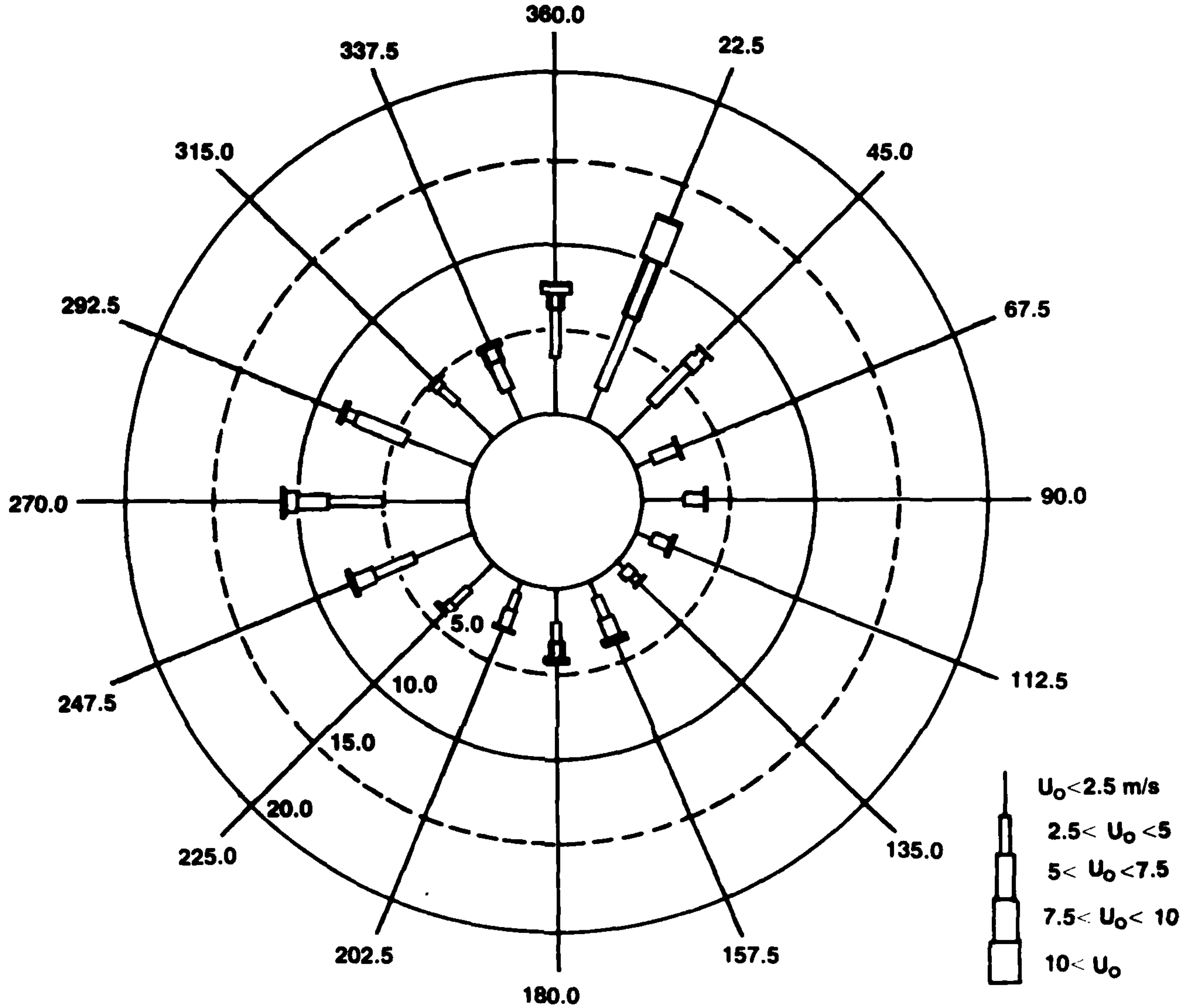

Figure 13 - Wind Rose for Mayport Naval Air Base for Winter 1984

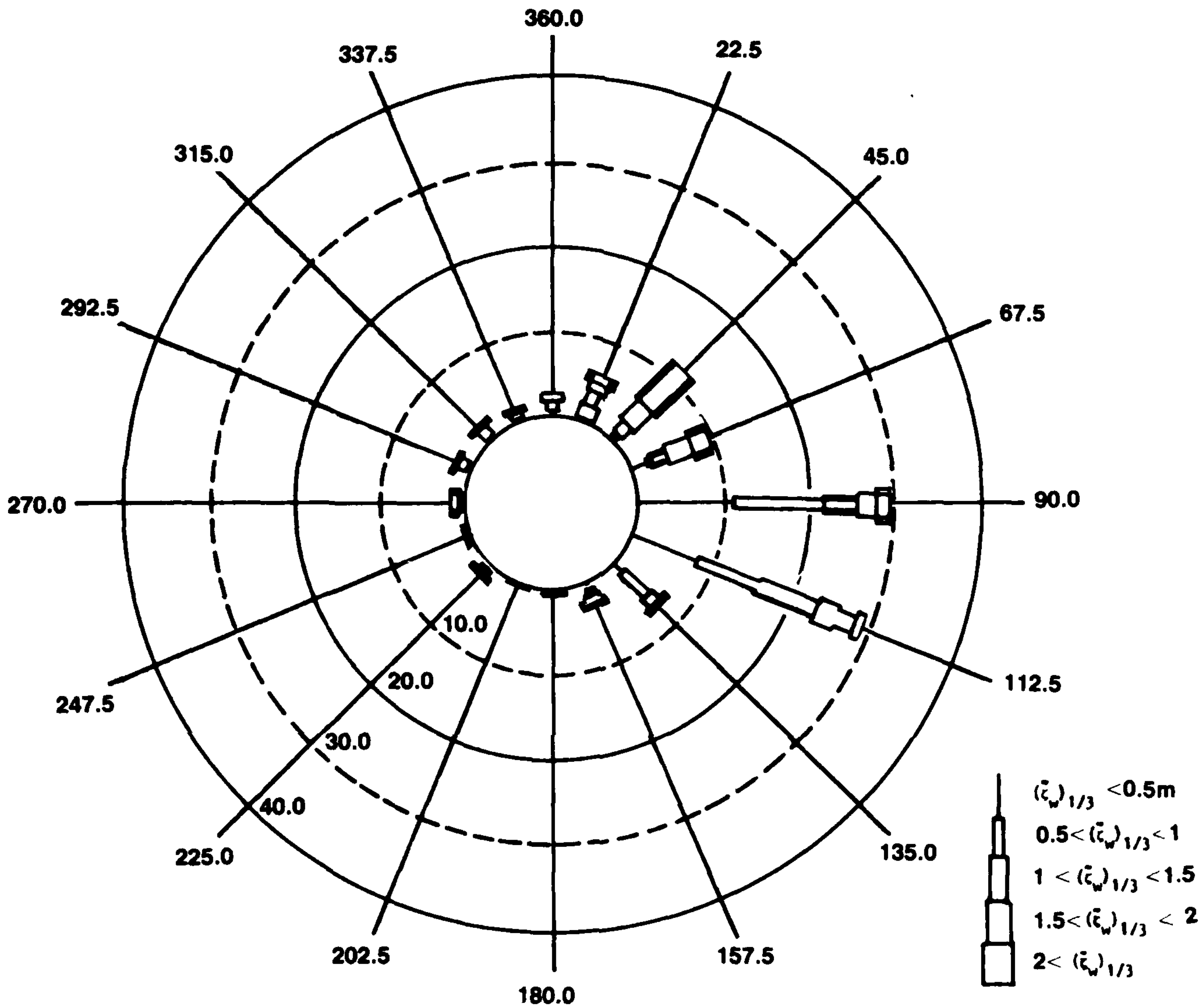

Figure 14 - Wave Rose for Kings Bay at Station 5 (Offshore) for Winter 1984

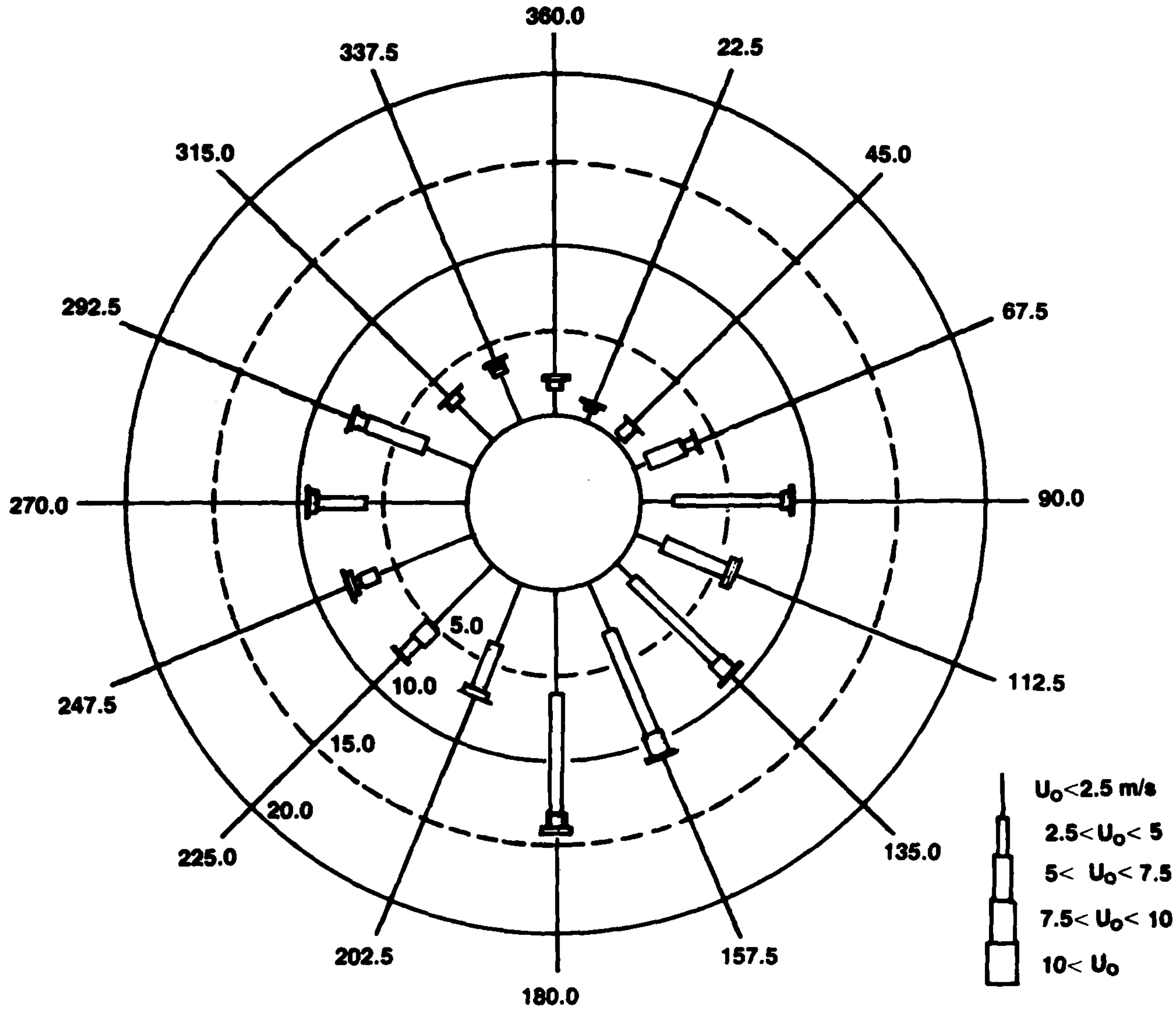

Figure 15 - Wind Rose for Mayport Naval Air Base for Summer 1984

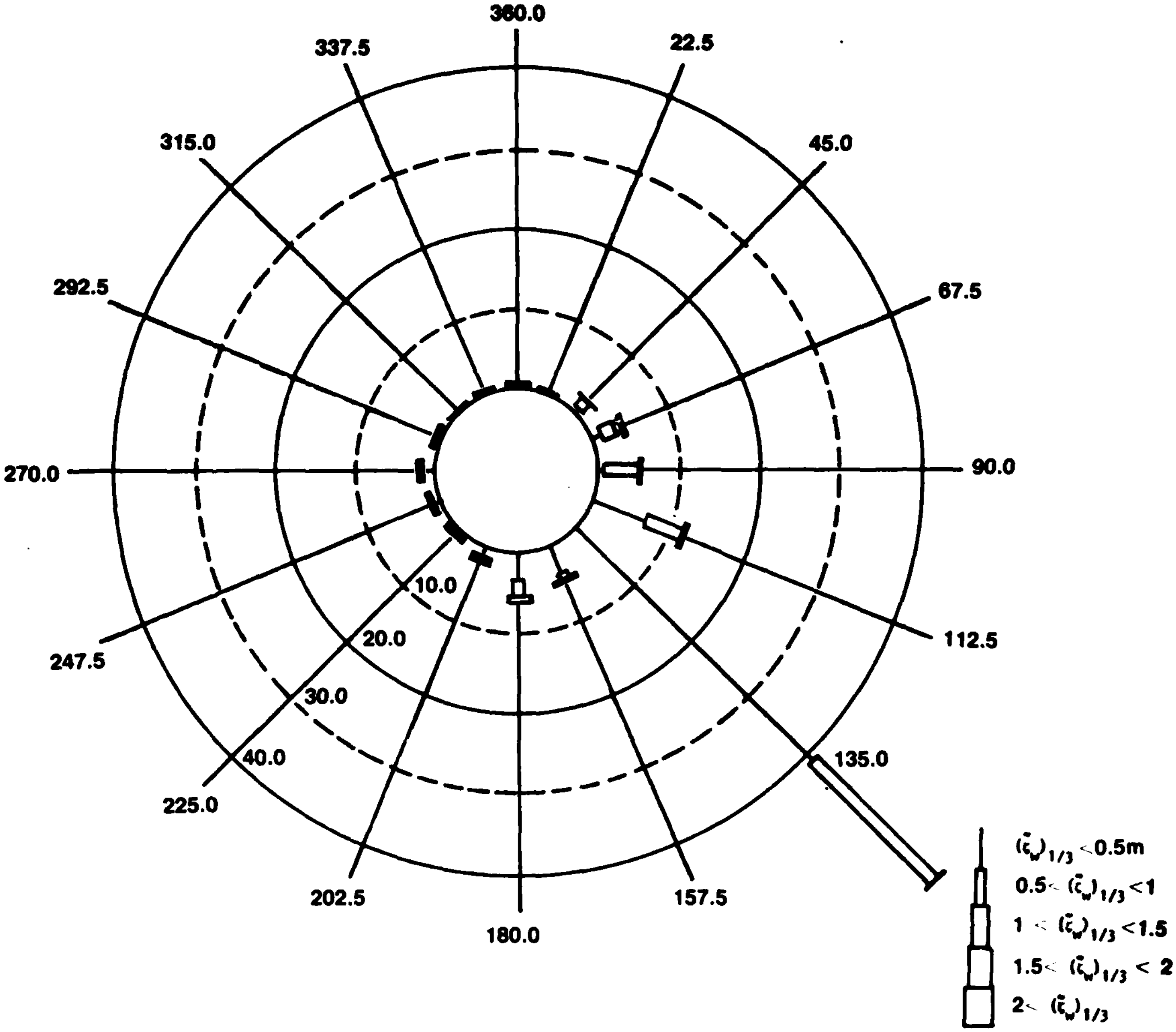

Figure 16 - Wave Rose for Kings Bay at Station 5 (Offshore) for Summer 1984

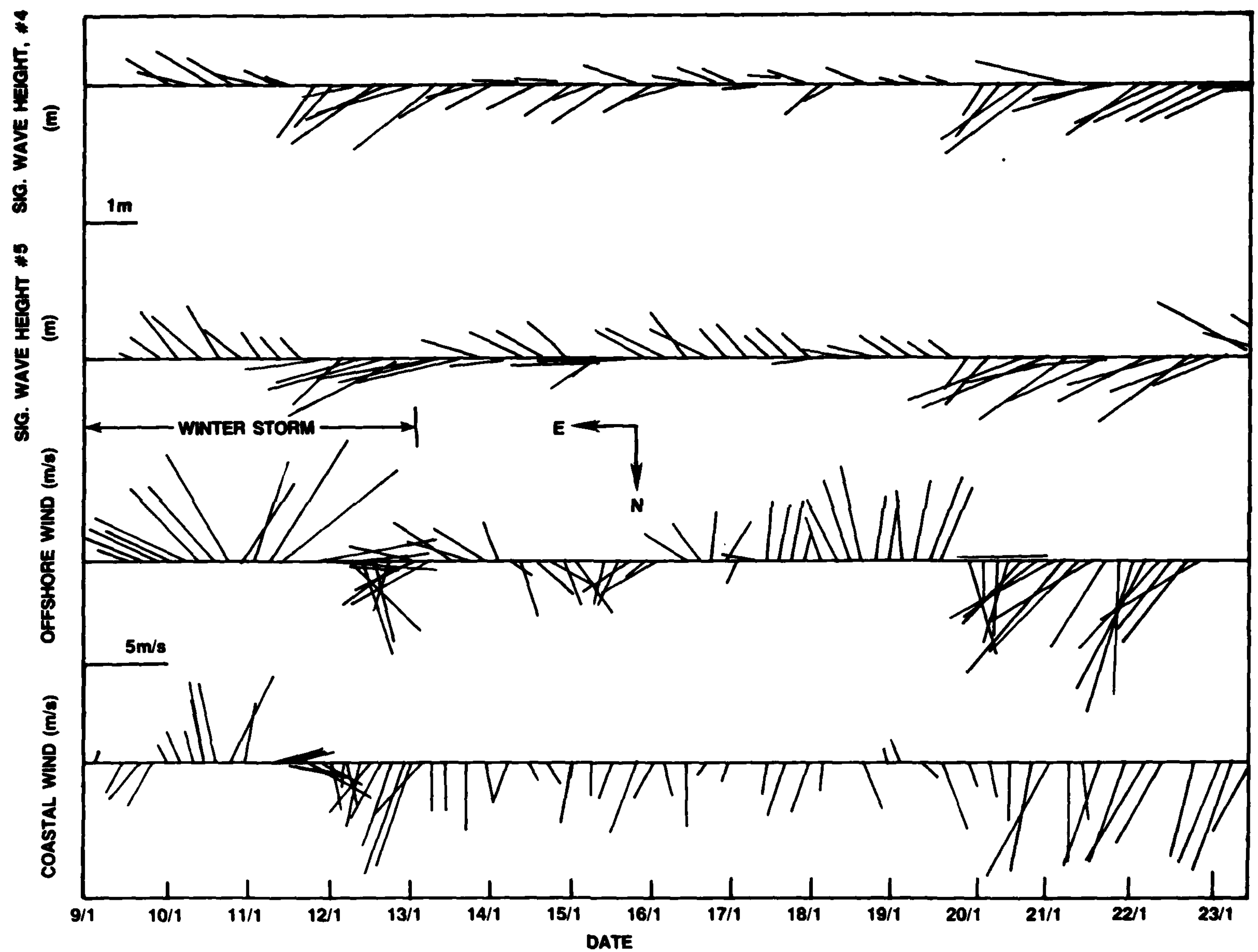

Figure 17 - Measured Wave at Stations 4 and 5 and Winds at Offshore Buoy (U_o) and Coastal Station (U_n)

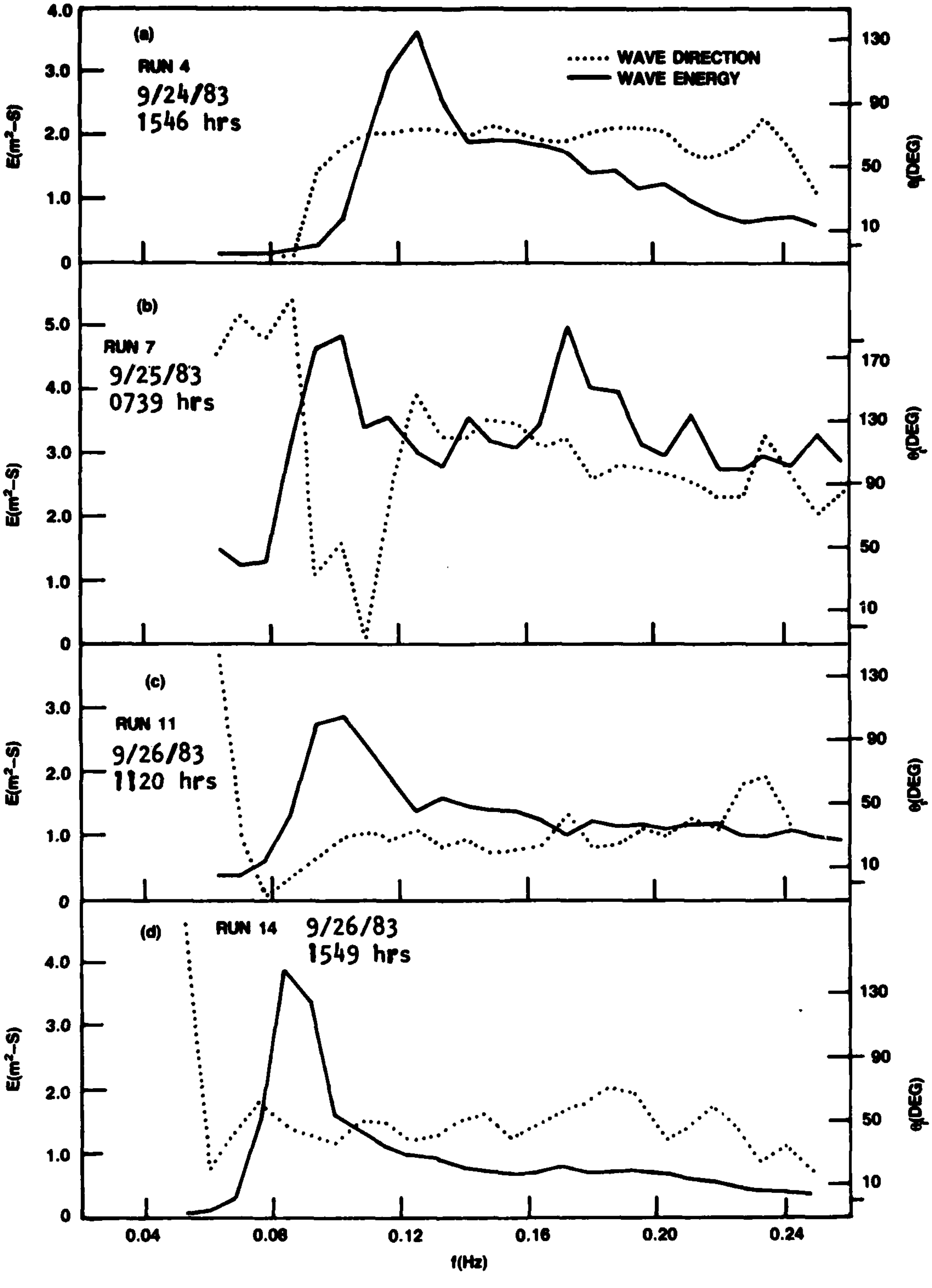

Figure 18 - Measured Wave Spectra with Mean Direction at Station 2 of Cape Canaveral During the Passage of the Storm of 1983

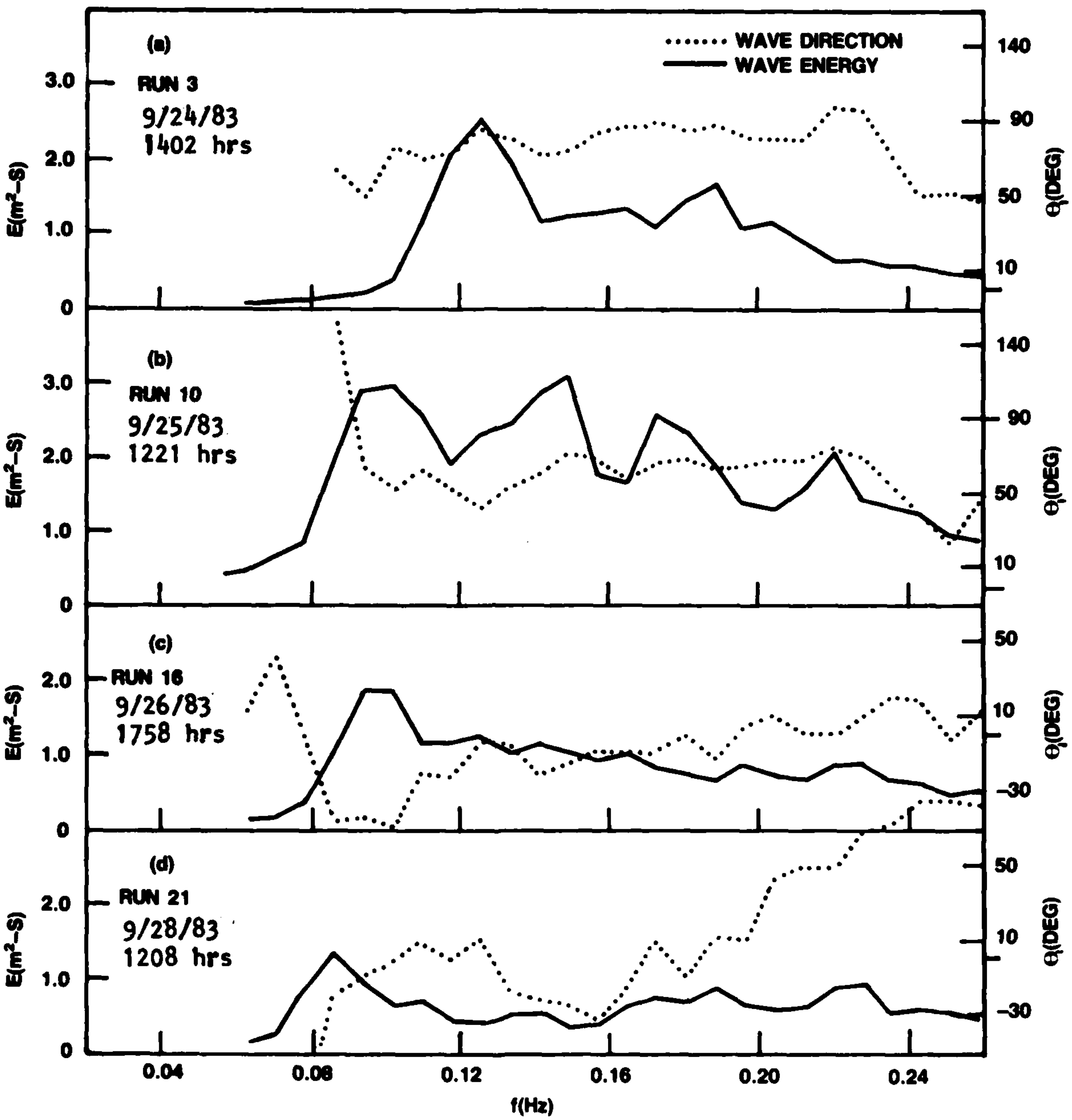

Figure 19 - Measured Wave Spectra with Mean Direction at Station 1 of Cape Canaveral During the Passage of the Storm of 1983

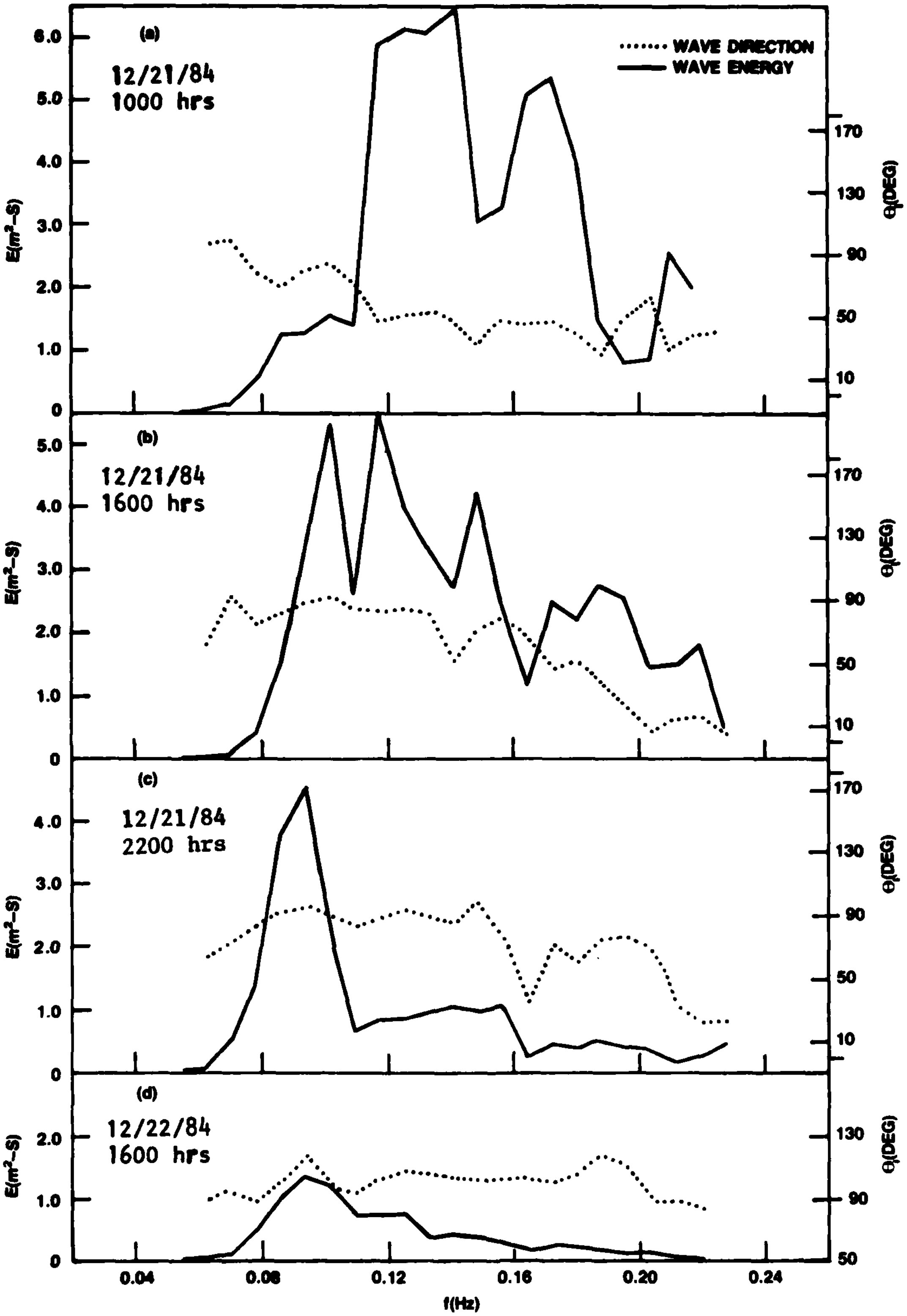

Figure 20 - Measured Wave Spectra with Mean Direction at Station 5 of Kings Bay During the Passage of the Storm of 1984

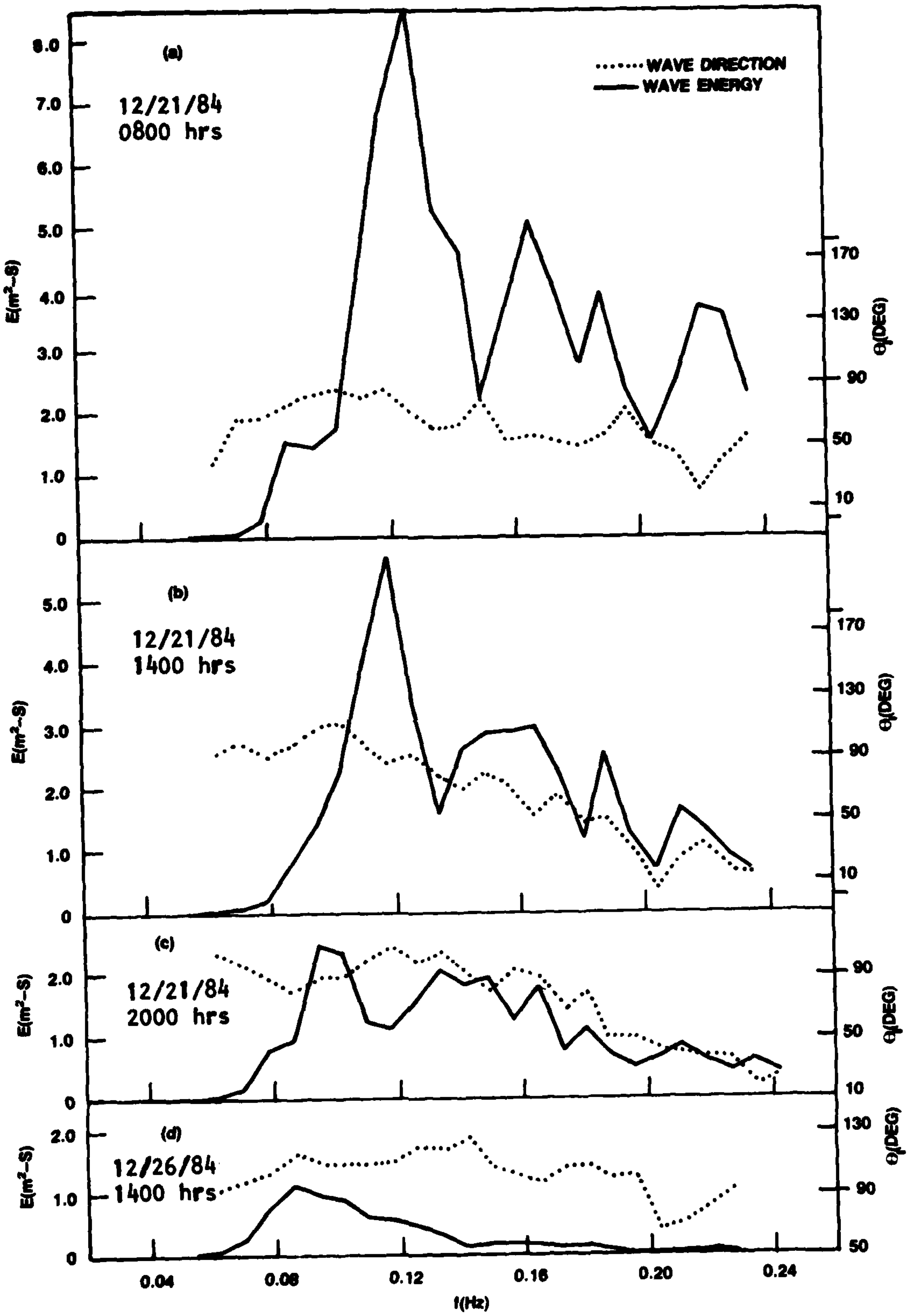

Figure 21 - Measured Wave Spectra with Mean Direction at Station 4 of Kings Bay During the Passage of the Storm of 1984

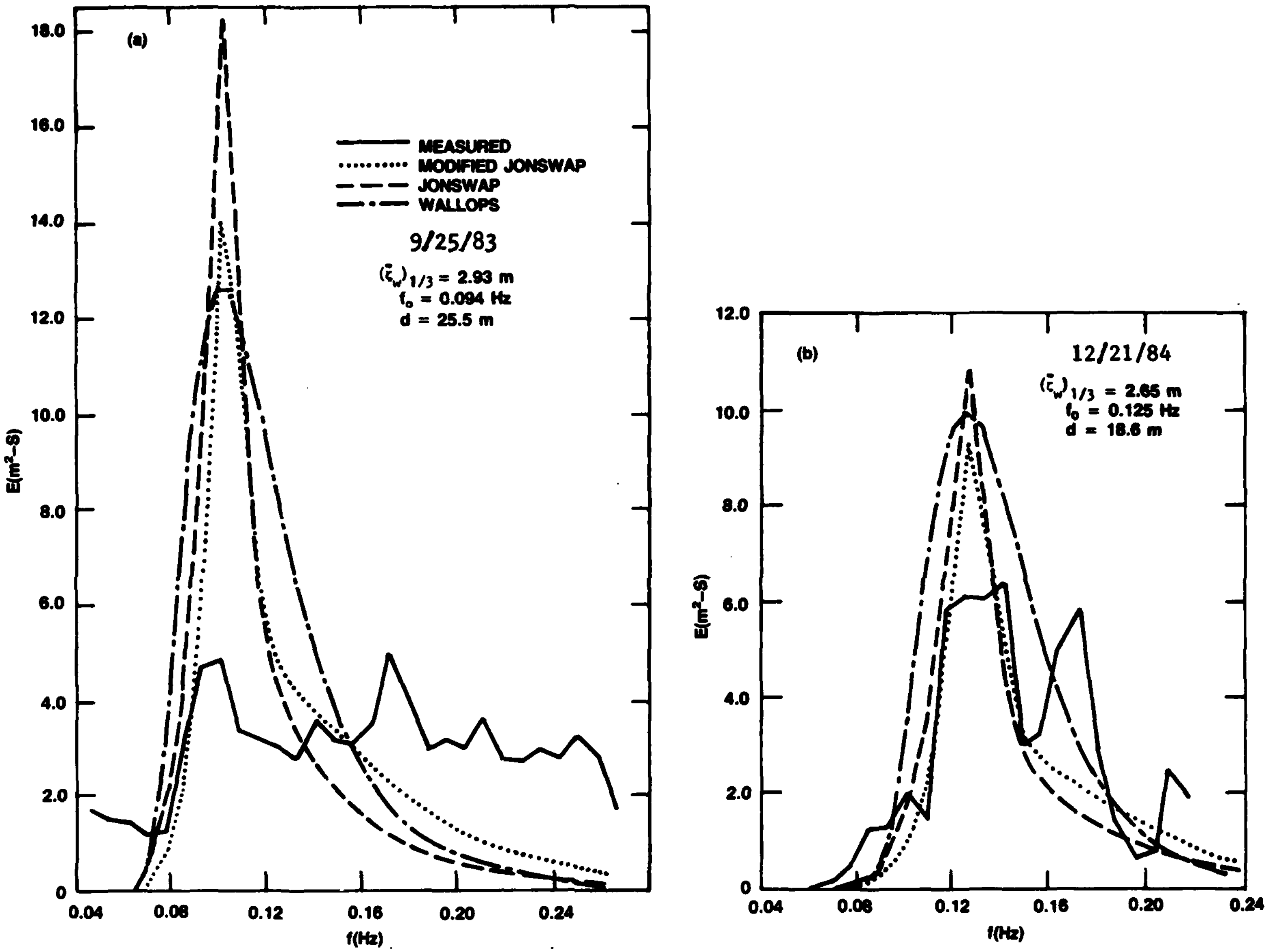

Figure 22 - Comparison of Measured Wave Spectra (Solid Line) with JONSWAP Spectra in Deep Water (Dashed Lines) and in Finite Water (Dotted Lines), and Wallops Spectra (Dashed-Dotted Line) at Cape Canaveral (a) and Kings Bay (b) During the Storms

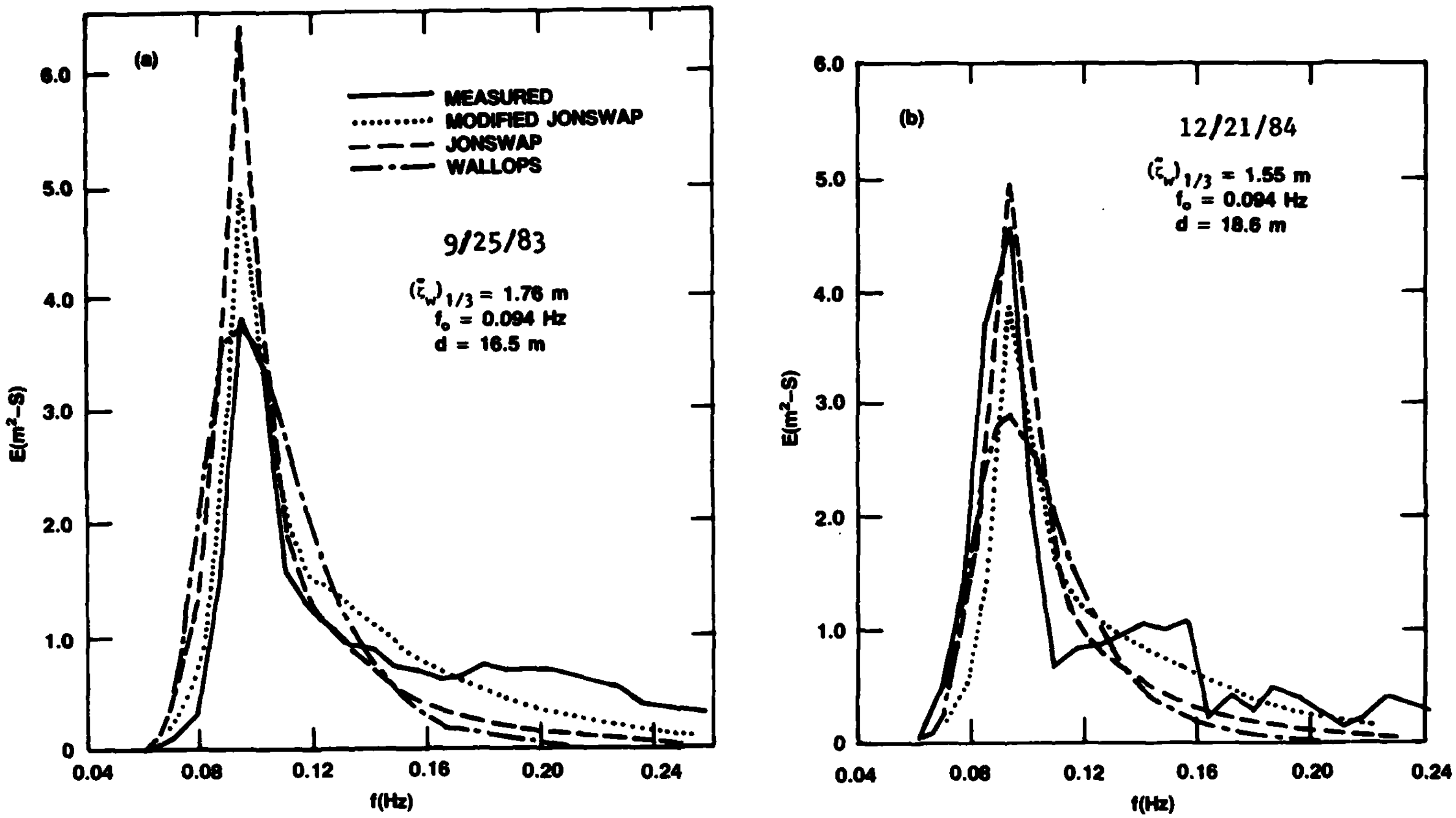

Figure 23 - Comparison of Measured Wave Spectra with JONSWAP and Wallops Spectra During Swell Sea at Cape Canaveral (a) and Kings Bay (b) During the Storms

TABLE 1 - WAVE GAGE LOCATIONS AND STATUS				
Station Name	Depth (m) (MLW)	Location	Data Format	Status (Recovery Rate)
Cape Canaveral (nearshore)	8.0	28 24' 42" N 80 34' 36" W	Point Spectra	1-1-82 to now (70%)
Cape Canaveral	17.0	28 20' 24" N 80 25' 12" W	Point Spectra	2 week operation replacement (<10%)
			Directional Spectra	4-1-84 - up to now (65%)
Kings Bay #4	15.0	30 42' 50" N 81 19' 00" W	Directional Spectra	12-1-83 - 2-5-85 (35%)*
Kings Bay #5	17.0	30 40' 31" N 81 16' 31" W	Directional Spectra	12-8-83 - up to now (60%)

*The system was found missing after several retrieval attempts and was replaced by a new one.

TABLE 2 - LOCATIONS OF ENDECO BUOY DEPLOYMENT AT CAPE CANAVERAL

Station No.	Depth (m)	Location	Set of Data Collected	Duration
1	12.8	28 22' 49" N 80 30' 55" W	18	9-24-83 to 10-3-83 1-6-84 to 1-18-84
2	14.9	28 20' 47" N 80 29' 36" W	20	9-24-83 to 10-3-83 1- 6-84 to 1-18-84
3	18.9	28 18' 48" N 80 24' 42" W	6	9-24-83 to 10-3-83 1-6-84 to 1-18-84
4	23.4	28 22' 30" N 80 19' 0" W	2	9-24-83 to 10-3-83 1-6-84 to 1-18-84

TABLE 3a - NEAR REAL TIME SIGNIFICANT WAVE HEIGHT AND MODAL PERIOD AT CAPE CANAVERAL

1983 - Cape Kennedy

Day	Time	Significant Wave Height (cm)	Modal Period (secs)
54	6:20	108.54	12.800
54	0:20	129.54	12.800
53	18:20	133.96	12.800
53	12:20	143.04	12.800
53	6:20	138.23	12.800
53	0:20	150.65	12.800
52	18:20	118.33	6.400
52	12:05	122.34	7.111
52	6:20	153.04	6.400
52	0:08	132.10	6.400
51	18:20	101.43	5.818
51	12:17	108.27	5.333

1983 - Cape Kennedy

Day	Time	Mean Depth (cm)	Significant Wave Height (cm)	Modal Period (secs)
54	6:20	828.7	108.5	12.80
		Frequency (Hz)	Energy (cm)	
		0.000	1.2156	
		0.016	9.0053	
		0.031	9.8121	
		0.047	19.0822	
		0.062	126.7626	
		0.078	131.8329	
		0.094	48.9454	
		0.109	28.8039	
		0.125	32.4473	
		0.141	64.9140	
		0.156	58.6520	
		0.172	33.1197	
		0.187	34.9474	
		0.203	42.7714	
		0.219	46.4782	
		0.234	39.8357	
		0.250	2.2251	
		0.266	1.1779	
		0.281	1.1922	
		0.297	0.9180	
		0.312	1.1690	

TABLE 3b - PERCENT ENERGY IN FREQUENCY BANDS FOR CAPE CANAVERAL
MAY 1984 MONTHLY REPORT

May 1984 Time Day	Hr	Dep (m)	Hs (m)	Percent Energy in Band, Band Period Limit (in secs): 21+	21-16	16-13	13-10.7	10.7-9.1	9.1-8	8-7.1	7.1-5.8	5.8-4
2	16	17.2	1.26	1.9	1.3	4.4	0.8	1.1	1.1	0.4	45.7	43.2
2	22	18.3	0.64	1.1	2.4	8.8	0.7	0.9	2.1	1.4	50.2	32.3
3	4	17.1	0.66	1.1	1.5	7.5	2.5	1.9	1.3	0.2	24.0	60.0
3	10	18.0	0.34	1.3	1.7	14.1	2.3	1.4	2.8	0.8	17.2	58.2
3	16	17.1	0.75	1.0	3.6	13.9	0.7	1.7	3.1	1.2	30.5	44.3
3	22	18.3	0.48	1.0	0.3	2.1	0.7	1.1	10.3	9.6	41.4	32.3
4	4	17.1	0.30	1.1	0.6	9.5	0.9	1.1	5.3	5.9	35.9	39.6
4	10	17.9	0.28	1.6	0.4	3.6	0.6	1.3	4.5	3.8	25.7	58.5
4	22	18.3	0.29	1.4	0.6	2.4	1.5	8.5	9.6	2.7	19.8	53.6
5	4	17.3	0.23	2.2	0.5	3.9	1.7	4.2	27.6	4.9	26.6	28.4
5	10	17.9	0.19	2.2	1.0	4.3	1.4	9.1	22.2	4.4	16.6	38.7
5	16	17.2	0.18	2.5	1.1	4.8	1.6	8.5	31.3	5.9	30.8	13.4
5	22	18.2	0.25	2.1	0.9	4.0	1.2	8.9	9.0	3.7	14.3	56.0
6	4	17.5	0.17	4.9	0.9	7.8	3.8	22.2	27.2	2.4	14.2	16.6
6	10	17.8	0.22	1.9	0.9	8.0	2.7	22.3	24.3	6.3	18.2	15.4
6	16	17.4	0.26	3.5	0.8	4.0	3.3	11.9	22.4	2.3	10.5	41.3
6	22	17.9	0.37	6.4	0.9	2.0	5.5	22.5	17.7	1.1	6.8	37.0
7	4	17.7	0.25	7.6	2.5	4.4	2.4	21.4	25.7	1.9	6.4	28.6
7	10	17.6	0.19	11.9	5.7	9.6	2.0	6.0	28.1	4.1	17.2	15.5
7	16	17.5	0.19	8.7	3.8	9.2	2.8	11.7	21.4	5.5	13.4	23.7
7	22	17.7	0.66	1.2	0.4	1.7	0.5	2.4	3.6	0.5	8.3	81.3
8	4	17.9	0.21	11.0	0.9	4.1	1.5	5.8	16.6	2.6	11.6	46.0
8	16	17.9	0.34	6.0	0.5	1.6	1.2	5.0	3.6	1.2	12.9	67.9
8	22	17.4	0.75	1.4	0.0	0.3	0.4	1.0	1.6	1.3	40.4	53.7
9	4	18.1	0.29	7.1	0.4	4.5	1.8	6.2	5.2	0.7	27.8	46.2
9	10	17.3	0.46	2.8	0.1	0.7	0.8	1.9	1.4	0.2	11.2	80.8
9	16	18,2	0.67	3.1	0.1	2.2	1.3	4.8	10.4	6.6	21.8	49.7
10	4	18.4	0.56	2.0	0.3	2.2	3.4	10.1	10.2	2.9	17.6	51.3
10	10	17.2	0.82	1.7	0.3	2.3	0.9	10.5	30.6	6.2	9.7	27.8
10	16	18.2	0.53	2.7	0.4	2.7	2.4	8.1	28.7	5.9	16.7	32.4
10	22	17.2	0.42	4.0	0.7	3.6	3.3	9.0	17.5	14.0	28.4	19.5

TABLE 4 - FORMAT OF DIRECTIONAL WAVE SPECTRUM

October 18 9:00
Station#:5 Time:84 292 9 Dep:17.0(m) Hs:0.69(m) Fm:0.070 Dir:0 Crnt:0.07(m/s)

f (Hz)	E(f) (m^2-s)	R1	R2	θ_1 (deg)	θ_2 (deg)	S
0.008	0.0031	0.05	0.13	275.	216.	0.16
0.016	0.0013	0.08	0.00	5.	230.	0.31
0.023	0.0019	0.08	0.12	5.	203.	0.31
0.031	0.0013	0.05	0.08	320.	275.	0.20
0.039	0.0013	0.12	0.08	347.	95.	0.59
0.047	0.0201	0.25	0.16	265.	306.	3.94
0.055	0.1232	0.26	0.14	263.	306.	4.08
0.062	0.3060	0.29	0.21	260.	289.	8.71
0.070	0.5799	0.29	0.21	263.	298.	8.68
0.078	0.4474	0.28	0.22	275.	324.	8.51
0.086	0.3713	0.28	0.23	270.	320.	6.99
0.094	0.3493	0.28	0.21	260.	296.	7.08
0.102	0.2752	0.28	0.24	265.	299.	8.16
0.109	0.3512	0.29	0.25	268.	307.	10.68
0.117	0.2105	0.29	0.25	268.	306.	9.02
0.125	0.1728	0.27	0.22	269.	312.	5.74
0.133	0.1188	0.28	0.24	274.	318.	7.43
0.141	0.1037	0.28	0.26	281.	332.	7.03
0.148	0.0735	0.26	0.23	278.	325.	4.28
0.156	0.0540	0.24	0.20	271.	324.	3.07
0.164	0.0515	0.23	0.15	277.	331.	2.58
0.172	0.0251	0.22	0.14	272.	317.	2.23
0.180	0.0226	0.22	0.13	285.	350.	2.11
0.187	0.0163	0.18	0.10	293.	3.	1.27
0.195	0.0138	0.10	0.06	264.	223.	0.49
0.203	0.0138	0.15	0.14	261.	277.	0.92
0.211	0.0145	0.08	0.12	285.	266.	0.36
0.219	0.0157	0.15	0.23	356.	130.	0.89
0.227	0.0132	0.18	0.17	345.	122.	1.24
0.234	0.0075	0.08	0.12	359.	91.	0.36
0.242	0.0057	0.03	0.15	275.	185.	0.09
0.250	0.0201	0.05	0.15	243.	175.	0.17
0.258	0.0182	0.04	0.09	11.	213.	0.12
0.266	0.0176	0.02	0.09	275.	167.	0.08
0.273	0.0151	0.05	0.04	320.	329.	0.20
0.281	0.0251	0.19	0.19	304.	22.	1.41
0.289	0.0591	0.09	0.10	90.	31.	0.38
0.297	0.0792	0.06	0.09	123.	166.	0.25

TABLE 5 - SUMMARY OF P-U-V DATA ANALYSIS FOR CAPE CANAVERAL (OFFSHORE), SEPTEMBER 1984

Day	Hr	Depth (m)	Hs (m)	f_o (Hz)	Current Speed (m/sec)	Current Dir (deg)	Wave Mean (deg)	Wave Sprd (deg)
1	6	17.2	0.24	0.13	0.071	343	96	31
1	12	18.5	0.25	0.12	0.077	356	101	28
1	18	17.4	0.24	0.11	0.032	353	100	29
2	0	18.2	0.31	0.12	0.044	332	105	33
2	6	17.3	0.32	0.10	0.037	301	99	28
2	12	18.4	0.34	0.10	0.034	289	104	24
2	18	17.6	0.37	0.11	0.047	145	102	34
3	0	18.0	0.31	0.10	0.031	276	105	23
3	6	17.4	0.33	0.11	0.021	155	101	27
3	12	18.2	0.33	0.11	0.055	251	92	33
3	18	17.8	0.38	0.07	0.039	166	102	27
4	0	17.9	0.34	0.12	0.054	233	95	33
4	6	17.7	0.32	0.07	0.038	260	107	32
4	12	17.9	0.27	0.07	0.075	301	93	34
4	18	18.0	0.32	0.07	0.052	14	81	33
5	0	17.6	0.36	0.12	0.085	323	111	21
5	6	17.9	0.26	0.12	0.080	352	92	24
5	12	17.6	0.25	0.07	0.088	319	82	39
5	18	18.3	0.22	0.07	0.039	99	95	32
6	0	17.6	0.26	0.08	0.038	241	102	25
6	6	18.1	0.31	0.23	0.150	197	14	27
6	12	17.6	0.22	0.08	0.049	217	94	30
6	18	18.6	0.65	0.19	0.154	208	32	26
7	0	17.7	1.28	0.11	0.217	213	53	27
7	6	18.4	1.08	0.10	0.100	202	52	28
7	12	17.6	1.30	0.11	0.077	208	53	37
7	18	18.7	2.45	0.10	0.072	219	49	25
8	0	17.7	2.47	0.09	0.058	215	38	25
8	6	18.5	2.26	0.10	0.075	213	57	24
8	12	17.6	2.29	0.09	0.097	210	52	27
8	18	18.6	3.16	0.09	0.108	196	44	24
9	0	17.7	2.78	0.09	0.128	204	54	29
9	6	18.5	2.21	0.09	0.091	220	49	23
9	12	17.7	1.35	0.11	0.095	204	82	30
9	18	18.6	1.08	0.09	0.059	228	55	30

TABLE 6 - SUMMARY OF PUV ANALYSIS FOR KINGS BAY, JANUARY 1984										
Station Number	Mon	Day	Hr	Depth (m)	Hs (m)	f_o (Hz)	Current Speed (m/sec)	Current Dir (Deg)	Wave Mean (Deg)	Wave Sprd (Deg)
5	1	11	4	17.2	0.67	0.14	0.029	326	145	29
5	1	11	10	17.3	0.55	0.12	0.212	342	140	22
5	1	11	16	17.5	0.45	0.11	0.021	180	140	32
5	1	11	22	17.5	1.55	0.13	0.076	59	85	25
5	1	12	4	18.0	1.32	0.23	0.207	207	43	42
5	1	12	10	17.5	1.73	0.18	0.154	223	75	27
5	1	12	16	18.0	2.38	0.16	0.286	209	77	24
5	1	12	22	17.4	2.47	0.19	0.269	218	66	36
5	1	13	4	18.4	2.03	0.13	0.201	218	80	26
5	1	13	10	17.4	2.10	0.16	0.226	222	76	30
5	1	13	16	18.2	2.09	0.24	0.162	225	78	29
5	1	13	22	17.0	1.23	0.09	0.099	241	107	20
5	1	14	4	18.5	1.09	0.14	0.056	276	88	27
5	1	14	10	17.1	1.09	0.09	0.056	262	115	19
5	1	14	16	18.2	1.09	0.09	0.014	151	119	22
5	1	14	22	16.9	1.00	0.09	0.064	225	131	21
5	1	15	4	18.7	1.43	0.18	0.082	265	84	29
5	1	15	10	17.2	1.27	0.24	0.223	211	62	43
5	1	15	16	18.2	1.59	0.16	0.116	253	89	33
5	1	15	22	16.9	1.13	0.09	0.237	208	120	22
5	1	16	4	18.6	1.28	0.09	0.097	305	117	20
5	1	16	10	17.2	1.11	0.09	0.199	204	142	28
5	1	16	16	18.0	1.16	0.10	0.071	298	116	28
5	1	16	22	17.0	0.76	0.09	0.121	196	128	32
5	1	17	4	18.3	0.91	0.09	0.118	348	138	22
5	1	17	10	17.4	0.75	0.09	0.156	191	126	29
5	1	17	16	17.7	0.87	0.09	0.143	347	131	17
5	1	17	22	17.3	0.75	0.09	0.135	182	131	18
5	1	18	4	17.8	1.04	0.19	0.121	328	72	30
5	1	18	10	17.8	0.87	0.19	0.146	200	94	35
5	1	18	16	17.2	0.83	0.16	0.109	345	103	30
5	1	18	22	17.5	0.66	0.10	0.142	170	125	20
5	1	19	4	17.1	0.65	0.12	0.203	355	125	17
5	1	19	10	18.1	0.38	0.09	0.038	149	120	34
5	1	19	16	16.8	0.43	0.10	0.150	350	128	22
5	1	19	22	18.1	0.77	0.24	0.051	120	36	31
5	1	20	4	16.6	1.23	0.21	0.103	271	44	29
5	1	20	10	18.8	1.62	0.17	0.179	217	63	29
5	1	20	16	16.6	2.53	0.14	0.380	219	70	24
5	1	20	22	18.6	2.61	0.16	0.245	216	68	29

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10-86

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